PUBLISHER'S COLUMN

Advertisers—more facts, please

As each of the first four issues of **CONTROL** have come from the printers, the 'atmosphere' of the magazine has always come to us as a surprise. We knew, of course, exactly what each of the editorial pages looked like since they had been carefully considered in proof stage.

This quality of surprise, we decided, came entirely from the advertisement pages since we had not seen many of them and, of course, had not designed them ourselves. They are a complement to the editorial pages and contain a wealth of information about the ironmongery of control systems and the components that go into them. But, advertisers and their agencies might perhaps take note of a letter which we publish this month (*Sir!*). A reader makes a plea for less hard-sell and more data. We think he is right. Our readers are intelligent folk and they want quite simply to know all the facts before they make up their minds.

CONTROL

OCTOBER 1958 VOLUME 1 NUMBER 4

MANAGING DIRECTOR ..... A. H. David Rowse, M.A.
EDITOR ..... Christopher T. Rivington, M.A., A.M.I.E.E.
ASSISTANT EDITOR ..... David E. Rayner, GRAD. R.AE.S.
NEWS EDITOR ..... John Woodeson, B.SC. (ENG.)
EDITORIAL ASSISTANT ..... Patricia Prince
PRODUCTION MANAGER ..... The Hon Gerald Vane, B.A.
PRODUCTION ASSISTANT ..... Gerald Withers
CIRCULATION ..... E. A. Hutcheson

EDITORIAL CONSULTANTS
Denis Taylor, PH.D., M.I.E.E., F.INST.P.
Reginald S. Medlock, B.SC., A.R.I.C., A.M.I.MECH.E., A.M.I.E.E.
John H. Westcott, B.SC. (ENG.), PH.D., A.M.I.E.E.
Maurice V. Wilkes, F.R.S.

ADVERTISEMENT DIRECTOR ..... Harry T. Kane
MIDLANDS ..... Arthur Lawless
NORTH ..... Harry C. Aikin
CLASSIFIED ADVERTISEMENTS ..... Barry Gibbs

IN THIS ISSUE

SPECIAL FEATURES

Heavy Instrumentation enables Better Papermaking 152
H. Wigman, B.Sc.

Control on Show
Farnborough: S.B.A.C. Exhibition 153
D. W. Allen
Geneva: Atoms for Peace Conference 158
K. W. Cunningham, B.Sc., A.M.Brit.I.R.E., A.Inst.P.

Making Transistors—by Autocontrolled Methods 163
Dr James Reekie, F.R.S.E., F.Inst.P., A.M.I.E.E.

Electrical Transducers—2 Tachometers and Tachogenerators 167
A. J. Maddock, D.Sc., F.Inst.P., M.I.E.E.

What is Control Engineering?—4 171
C. M. Burrell, M.A., B.Sc., A.M.I.E.E. and J. K. Lubbock, M.A., B.Sc.

Fast-Response Magnetic Amplifiers 176
E. H. Frost-Smith, B.A., Ph.D., A.M.I.E.E.

REGULAR FEATURES

Publisher's Column	A1	Control Survey—4	183
Leader	A27	Control in Action	187
Industry's Viewpoint	151	Pick-off	190
Letters to CONTROL	A29, A31	News Round-up	191
Data Sheet—4	161	New for Control	196
Looking Ahead	166	People in Control	202
Industrial Publications	182	Inventions	202
Classified Advertisements	A49 A51	Index to Advertisers	A52

© 1958

ROWSE MUIR PUBLICATIONS LIMITED
3 PERCY STREET, LONDON W1, MUSEUM 8252

Tick **No 3** on reply card for further details

120 HOURS A WEEK

Non-Stop!

We specialize in the design and manufacture of automatic sequence control panels and have supplied them to practically every industry.

This Control Panel has been designed and built for the sequence control of synthetic resin coated sand processing. The machine operates 5 days a week—day and night—non-stop producing 1½ tons of coated sand every hour. After loading the hoists the Panel automatically controls all process operations including discharge into the sacks. The Floor Mounted Controller incorporates H.R.C. fuses and heavy duty automatic starters for all motors which total 100 horse power. Mounted on the Panel are 6 visible continuously adjustable dial process timers with tamper proof operation counter giving full automatic control of the coating operations with manual control for sampling. This method of automatic control definitely reduces production costs. Scrap caused by incorrect mixing by hand is entirely eliminated and uniformity in batch production constantly maintained.

May we receive your enquiries - We are confident that our suggestions will save you time and product cost!

Send for our catalogue illustrating special panels and complete range of Standard Motor Control equipment.

Illustration shows the compact design of the B.K.S. Panel.

BKS

SPECIALISTS IN ELECTRICAL CONTROL

post this coupon today

BRITISH KLOCKNER SWITCHGEAR LTD.
HEAD OFFICE & WORKS: **CHERTSEY, SURREY.**
Telephone: Chertsey 3467

LONDON:	Refer to Head Office.
MANCHESTER:	Cromford House, Cromford Court, Manchester 4. Tel: BLAckfriars 3903.
GLASGOW:	249, St. Vincent Street, Glasgow C.2. Tel: CENtral 2479.
NEWCASTLE:	Mr. H. Breeze 4, Beechwood Avenue, Monkseaton, Whitley Bay, Northumberland. Tel: Whitley Bay, 24231.
BIRMINGHAM:	Mr. J. Perry, 45, Streetly Crescent, Four Oaks, Sutton Coldfield. Warwickshire. Tel: Streetly 1641
DUBLIN:	Mr. H.E. Kilbride-Jones, 11, Crow Street, Dublin. Tel: Dublin 71717.

To BRITISH KLOCKNER SWITCHGEAR LTD.
CHERTSEY, SURREY.

Please send me your latest comprehensive catalogue.

NAME.....

POSITION.....

FIRM.....

ADDRESS.....

C/10/58

.....

CONTROL OCTOBER 1958 VOL 1 NO 4

Under- or Post-graduate?

LIKE LEAVES IN VALLOMBROSA, REPORTS, articles, speeches on technical education have fallen thickly on scientists and engineers since the war. No annual scientific conference, no professional engineering society, no technical journal, no public-speaker-just-returned-from-Moscow can be said to have neglected the subject. Many who are alive to the deep-seated weakness of Britain's economy must have longed for more action, less talk. Yet, though large sections of the public are still apathetic about producing more technologists in this country, the perennial discussion has had some effect: successive governments have been stirred to give a politically unimportant subject more attention than they would have otherwise.

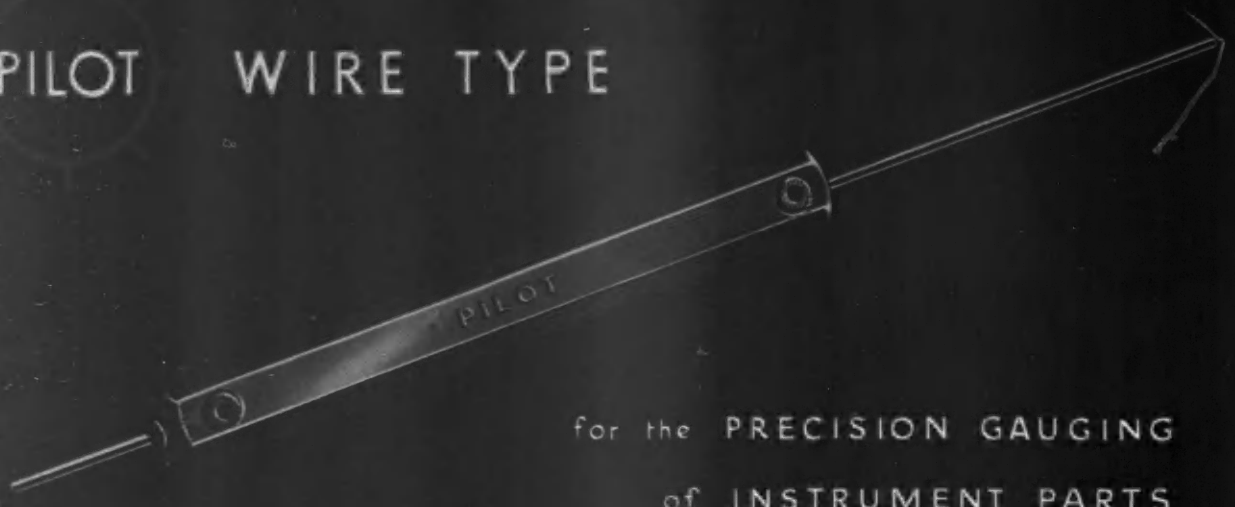
Now in several ways this attention is bearing fruit. Not least of these is in new awards, for about three weeks ago the first Dip.Tech.(Eng.)'s were obtained by some thirty students who had successfully completed a GEC-based sandwich course in electrical engineering at Birmingham. Twenty-five other engineering courses recognized by the Hives Council are now in being, and in the next few years a widening stream of mechanical, electrical, chemical and aeronautical engineers will flow from these to supplement the university output. Excellent. But turning from these older technologies to a young one, what is being done about training control engineers at undergraduate level? The answer is 'very little': there is, we believe, only one full-dress course in the subject—at the Northampton College of Advanced Technology. No British university known to us allows specialization in control engineering in the third or fourth year on a par with civil, electrical, mechanical or aeronautical engineering.

Should more be done? Here we enter controversial ground. Many educationalists, many senior engineers in industry, are fairly content with present arrangements: control engineers—often basically electrical, sometimes mechanical or chemical, sometimes ex-physicists—receive college education in engineering science with a slant towards electronics and servos in their final year; they do a general apprenticeship; and later they pick up their detailed knowledge of instruments and system analysis on the job. Other people who think ahead, strongly led by Sir Harold Hartley in his now famous address to the Society of Instrument Technology last May, would start first-degree courses in control engineering. Let CONTROL's view be clear: we support Sir Harold (though we disagree about control engineering being a 'primary technology'). And we emphasize his insistence on mathematics and fundamental engineering science being taught during the first two years of an undergraduate course in control engineering, as it normally is to aspiring mechanical or electrical engineers. This is essential: the control engineer must be an engineer first—a control engineer second.

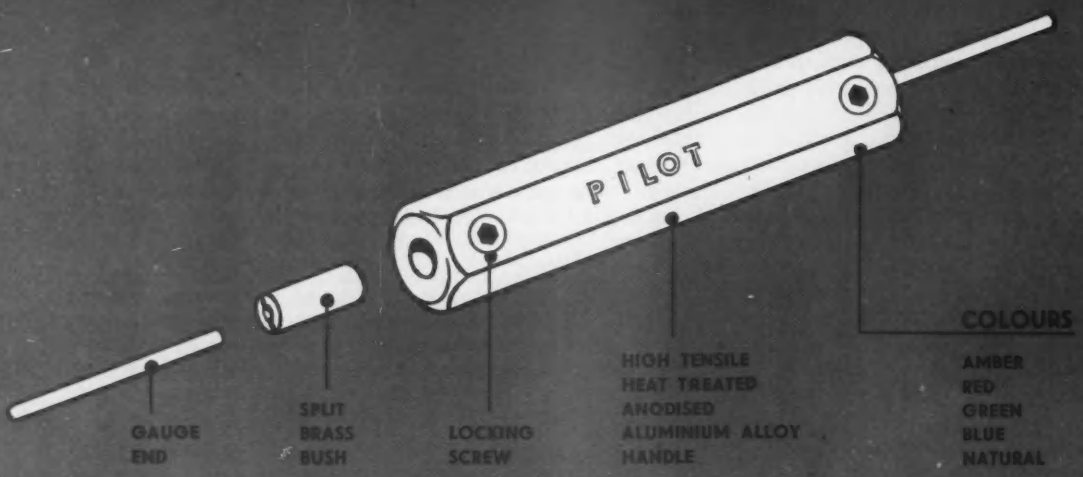
Twofold advantage is to be gained from directing the undergraduate's thoughts towards control systems engineering as a subject in his third (and, if available, fourth) year. First, control engineering cuts across the work of most engineering departments in a university; no good reason allies it to the electrical engineering department, though electrical engineers often make the best system analysts. Secondly, it is a unifying subject. It is proper for the student engineer to start thinking in terms of feedback, transfer functions, digital techniques, information theory, without reference to specific equipment. In a world of deep specialists the control systems engineer must be something of a 'generalist'. No doubt present methods produce admirable control engineers—in time. But the expansion of autocontrol in industry, and the development of complicated systems involving both control and communication will cause a shortage of systems engineers, unless we revise our methods. There will not be time to give all the required training in postgraduate courses. The University Grants Committee in their recent report are sanguine that by the late 1960's Britain will be producing sufficient scientists and technologists in general. But only by planning new courses now will those responsible ensure enough control engineers.

We urge therefore that heads of departments in universities and technical colleges should question whether they are providing enough training in control engineering. All honour to the Northampton CAT for establishing the first Dip. Tech. (Eng.) course in the subject. Britain needs more sandwich courses of this type and a few first-degree university courses. Control engineers have a crucial role in the increasingly automatic Britain that lies ahead.

PILOT WIRE TYPE



for the PRECISION GAUGING of INSTRUMENT PARTS



RANGE	DOUBLE END COMPLETE		REPLACEMENT ENDS	
	CHROME	STEEL	CHROME	STEEL
.000" – .010"		45/-		20/-
.011" – .020"		40/-		18/-
.021" – .250"	45/-	35/-	20/-	15/-
.250" – .500"	57/-	43/-	26/-	19/-

The lengths of the gauge ends vary with diameter and are from 1¼" to 1¾" long. Because they are parallel, the worn front end in the smaller sizes may be cut off and the gauging member fed a little further out of the handle.

Alternatively it can be turned end for end.

PILOT holds at least 50,000 of these high precision gauges in stock for immediate delivery when required.

PILOT
PLUG GAUGES

SWALLOW RD., COVENTRY
TEL. 88894

Tick **No 29** on reply card for further details

SIR! LETTERS TO CONTROL

The Editor welcomes correspondence for publication

Numerical control of machine tools

SIR: I read with interest the article by Mr Williamson on computer control of machine tools, but feel that in fairness to potential users of electronic control systems it should be pointed out that in a number of instances the author's conclusions on interpolating systems appear to be based on incorrect information.

The article contains a number of ambiguities which need clarification; for example, that a normal engineering co-ordinate drawing shows the coordinates of change points. This is not at present the case, and the coordinates of change points have to be calculated, both for the Ferranti system and others.

Figs. 3 and 4 (July) can be misleading. The cutter-centre path in Fig. 3 has a set of data points shown along it. It is obviously unnecessary to calculate a set of data points for both work profile and cutter path. In practice the dimensions of the cutter path are calculated (e.g. by adding the tool radius to the radius of a circle), and the data points are then worked out for the cutter path only.

In the final paragraph of Section 2.2.2. (July) the author states that 'cutter compensation, if available, is confined to small adjustments intended to cover the change of size when a cutter is reground'. An adjustment of up to 0·300 in. (provided in a particular system in mind) can hardly be described as small. This dimension, which is limited only by the accuracy required, is useful for making roughing cuts, allowances for cutter deflexion as well as adjustment for reground cutters. It is also advantageous that adjustments can be made at the machine without further reference to an external computer.

In Section 3.2 (August) Mr Williamson states that the use of lead-screw measurement 'limits the reliable resolution to about 0·005 in. on a small machine'. It is now possible to buy hardened and ground ball screws with a pitch error of not more than 0·0005 in. per foot. Over 30 in. (a maximum for a small machine) this would mean a maximum cumulative error of 0·00125 in. but analogue systems such as those marketed by EMI can correct entirely for mean pitch error, and the maximum possible residual error is then less than 0·00075 in. Furthermore these same screws, adequately preloaded, reduce lost motion between screw shaft and table to less than 0·001 in.—normally 0·0005 in. Mr Williamson's figure of 0·005 in. is therefore several times too high.

I hope that these comments will help to clarify any misconceptions that may have arisen in your readers' minds.

EMI Electronics Ltd R. H. BOOTH

● *Thank you, Mr Booth. Readers may like to know that we expect to publish soon an article on the EMI system of numerical control of machine tools. Meanwhile perhaps we shall hear some more from Mr Williamson*—EDITOR

My own copy

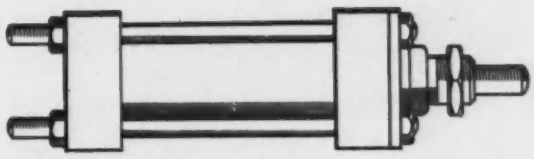
SIR: For the last two years I have mentioned to many people our need for a journal specifically on instrumentation and control engineering.

Although I started my career as an electrical engineer, I became a member of the Society of Instrument Technology to meet people working in this sphere. Later I found that in order to keep fully up to date in electronics and automation I had to join one further professional institution (The British Institution of Radio Engineers).

When I first received a specimen copy of the first issue of

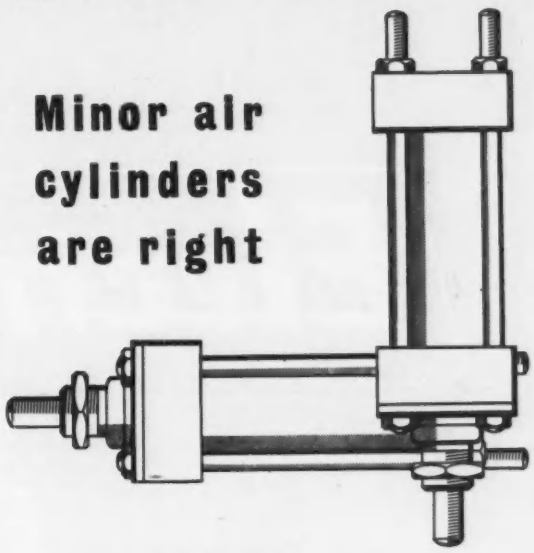
Tick **No 30** on reply card for further details

WHATEVER THE ANGLE

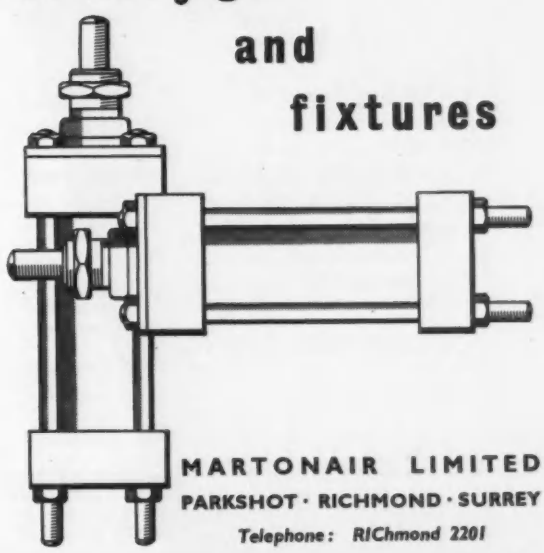


MARTONAIR

Minor air cylinders are right



for all jigs and fixtures



MARTONAIR LIMITED
PARKSHOT · RICHMOND · SURREY
Telephone: RIChmond 2201

Tick **No 31** on reply card for further details

Automatic Controls for

OIL REFINERIES
CHEMICAL PLANTS
BOILERS
KILNS & FURNACES
WATER & SEWAGE SCHEMES
GAS MANUFACTURE & DISTRIBUTION
PROCESSES

Automatic Control

Electrofio

Instrumentation

Instrumentation

FLOW METERS
AUTOMATIC REGULATORS
Pneumatic, Hydraulic, Electronic
AUTOMATIC PROCESS CONTROLLERS
POTENTIOMETERS
RESISTANCE THERMOMETERS
TELEMETERING EQUIPMENT
TRANSMITTERS
PANELS - CUBICLES

Complete Installations Designed, Manufactured, Installed and Serviced.

Prompt attention to your enquiry will be given by Head Office: Abbey Road, Park Royal, London, N.W.10. Phone: Elgar 7641/8. Grams & Cables: Elflometa, London, Telex. Factories: Abbey Rd., Standard Rd., & Minerva Works, Chase Estate, Park Royal and Maryport, Cumberland. Engineer Representatives in all areas. Agents in all principal countries throughout the world.

Member of Elliott-Automation Group

SIR!

CONTROL, I immediately requested our librarian to put an order in to your good selves. Several of my colleagues read through your journal and endorsed my praises. I have only just finished reading No 2 and on reading No 3 I feel I cannot do better than to have my own copy each month.

Shenstone, Staffs J. F. WINTERBOTTOM

● *D'accord!*—EDITOR

A clear answer?

SIR: When discussing the relative merits of pneumatic and electronic operation for instrumentation and control, the supporters of pneumatics inevitably try to list the functions which pneumatics can *also* perform, rather than submit examples for which electronics is not suitable. But quite apart from the standard reasons, the case for electronics is ever growing, particularly in view of the now general necessity for additional facilities, such as end-product analysis, high-speed monitoring, digital and analogue computing etc, to name but a few. These auxiliaries are electronic or electrical throughout, and their increasing application clearly shows where the future lies.

Even when impartial analysis of the requirements of the plant to be controlled has shown that pneumatics and electronics may serve equally well, the requirements of the accountant, to name only one of many, for processed output figures presented in a particular form, will really determine the issue.

Moreover, where in the past a plant has been equipped with electronic equipment, operators are able to avail themselves, without significant alterations to their installation, of additional instruments and new facilities.

All these points provide a clear answer to what, at first glance, may appear to be a controversial question.

Eversheds & Vignoles Ltd. ERNEST D. MAY

● *Can a pneumatic protagonist—preferably a user—take up Mr May's point and let us know some control functions for which electrical engineering is not so suitable? We suspect that flow valves were in some readers' thoughts as they read Mr May's letter. The poor accountant—he is always safe game in an engineering controversy*—EDITOR

New facets, new ideas

SIR: Turning the pages of a new journal dealing with one's own subject has a special pleasure due to that newness; one wonders how the editor and his contributors are going to treat the subject; what new facets of the field they are going to illuminate, what new ideas one is going to meet. CONTROL is still sufficiently new for those questions not yet to be fully answered, and I therefore write to express the hope that you will be able to combine articles on subjects such as operational research, both practically as for example in traffic control systems and theoretically, as in subjects such as linear programming; random processes as applied to servos; non-linear servos and methods of analysing their behaviour.

I should also like to see a monthly survey of original literature on control and feedback matters of every kind. In such a survey I should hope to find abstracts of articles on mathematical techniques of use to control engineers.

Perhaps in time, who knows, you may even persuade your advertisers to give up promotional advertising in favour of providing genuine technical information. Your paper contains examples of both kinds, with plenty in the middle of the road.

Watford R. A. LAWS

Tick **No 32** on reply card for further details

These few instruments demonstrate the work of

SHORT & MASON LTD.

in designing, manufacturing and supplying instruments of all kinds for industrial use . . .

Mercurial barometers — new 100,000-ft. model is now available of robust construction square column and wide base. Kew and Fortin types also available.

Mercury-in-glass Thermometers — - robust, simple and sensitive under severe operating conditions; easily read magnifying tube. Supplied with union connection hub, flange or separable well or any of many other fittings. Straight Stem and Front Angle (90°), Left-Right-Side and Oblique Angle models.

Many other thermometers available — max. and min. registering, Anschutz and Beckmann, pocket and test thermometers, thermographs and hygrometers. Many to B.S. and other specifications.

Permafuse — a new process of fusing the graduations, etc., permanently on to the glass has been developed so that they withstand attack from a large range of chemicals, including concentrated acids.

Vane and Cup Anemometers — wide range of readings and speeds. Vane models incorporate jewelled movements, disconnector, zero-setting and come complete with correction chart in leather case. Electric Cup model provides remote indication of *instantaneous* wind speed.

Drage 'Multi-Test' — a new tensile compression or bending testing machine. The test sample may be subjected to deformation, oscillating loads or held under constant load. Double pen recording system enables two functions to be plotted against a third (e.g. extension and load against time). Measuring heads range from 0.5 gms. to 50,000 gms. capacity.

Drage Viscometers — include provisions for measuring liquids under high pressure or at high temperatures. Submersible systems are available for use with open or closed tanks.

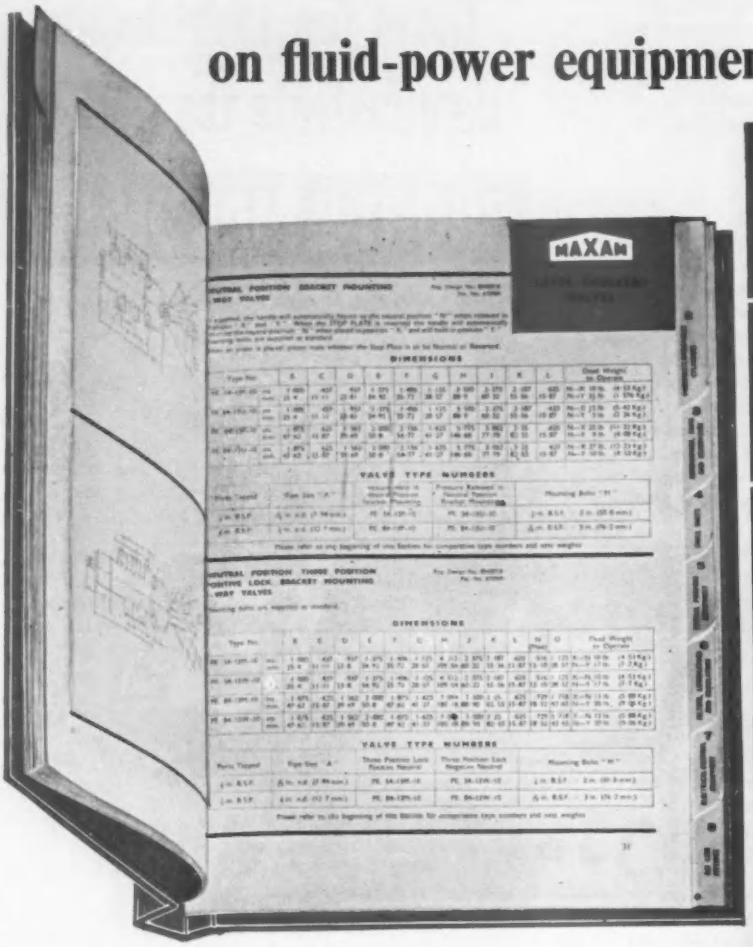
SHORT & MASON LTD. — are also equipped to undertake the development and production of special instruments, and to modify existing instruments for specific applications.

MAKERS OF: BRASS CASE BAROMETERS - THERMOGRAPHS - MERCURIAL BAROMETERS - HYGROMETERS - THERMOMETERS - HYGROGRAPHS - WIND SPEED AND DIRECTION INDICATORS - RAIN GAUGES - GAS MEASURING INSTRUMENTS - DURATION OF WETNESS RECORDERS

SHORT & MASON LTD., Aneroid Works, 280 Wood St., Walthamstow, E.17. COPpermill 2203/4

Tick **No 33** on reply card for further details

Maxam offers a detailed reference book on fluid-power equipment



- Lavishly illustrated with top-quality photographs.
- Full specifications and scaled draughtsmen's plans of every unit.
- Comprehensive sections on: control valves; pneumatic/hydraulic cylinders; intensifiers, rams and reservoirs; drill units . . .
- . . . special-purpose equipment; filters, lubricators and regulators; electrical control equipment; airline fittings.

FREE to Chief Engineers, Methods Engineers, Plant Engineers, Designers, Draughtsmen, Buyers and Librarians.

FULL PLANS AND SPECIFICATIONS OF MAXAM EQUIPMENT

Just post the coupon below or write for your copy.
Take a tip from MAXAM and write in now, for supplies are limited and there's going to be a big demand.

MAXAM POWER LIMITED

Camborne, England. Telephone: Camborne 2275 (10 lines)
44 Brook St., London W.1. Telephone: Hyde Park 9444

A company in the Holman Group which has branches, technical representatives and agents throughout the United Kingdom and the world.

To: MAXAM POWER LIMITED, CAMBORNE, CORNWALL.
Please send me the new Maxam publication, 166A.

NAME .....

POSITION .....

BUSINESS ADDRESS .....

.....

C.2

INDUSTRY'S VIEWPOINT

A monthly article by a prominent man in the control industry on a subject chosen by himself

QUALITY CONTROL— THE NEXT BIG STEP

by **LEON BAGRIT**

Managing Director, Elliott-Automation Ltd

WHEN A SYSTEMS ENGINEER SPEAKS OF 'AUTOMATION' or of the 'fully automatic process', he means a plant which is self-optimizing and which will therefore produce a product of known, consistent quality at the highest efficiency possible for that plant. In the struggle for markets, so crucial to this country's economy, it goes without saying that the quality of our products must be high. At the same time, production efficiency must be increased if prices are to remain competitive. These requirements would seem at first sight to be somewhat conflicting, but the surprising thing is that in a properly formulated scheme of automation they do, in fact, go together.

The basic concept underlying all such developments is, of course, that of feedback—in this case the detection of imperfections in the quality of the output product and the employment of the information in restoring such quality. This sounds simple enough, but in most chemical processes, for instance, the relationships existing are so complex that much research is required before the right use can be made of such feedback. There are many intermediate steps to be taken before the final loop can be completed, and it is in this area that, so far, most progress has been made. The instrument industry has contributed a great deal in this field, both independently and in co-operation with the various user industries. As a result measuring, data-processing, computing, and actuating equipment which can perform most intermediate functions required in automatic control systems is available commercially.

It is in the light of such developments that the chemical process engineer is now turning his attention to the continuous measurement of output product quality. Laboratory analysis instruments have been in use for routine sample checks for many years; but the results of such tests can influence only the 'average' product quality, since, first, the information is obtained well after the event, and, secondly, the problem of interpreting a final product deviation in terms of compensatory adjustments to the plant is, in the absence of a suitable computer, often too complex for quick solution. Thus, whilst the plant can be controlled to take account of long-term effects, hour-to-hour fluctuations affecting both quality and efficiency cannot be closely controlled. If the possibilities of continuous optimization now being opened up are to be exploited, the output product stream must be analysed continuously and the data so obtained effectively used in controlling the process.

Therefore the next important step to be taken in the field of chemical plant automation is the introduction of quality analysis instruments capable of completely defining the output product, and suitable for continuous use on the process stream.

Much progress has been made and good 'on stream' instruments are already available. The problem of hazard is receiving particular attention, and, in several instances, the section of the equipment which must be located on the plant itself is housed in an explosion-proof container and separated from the associated control unit. The whole field is growing but is very costly to develop, requiring in some cases the building of 'chemical micro-plants', fully equipped with quality analysis instruments, computers and controllers, for carrying out experiments in the use of fully automatic control and for the development of the new quality control instruments and associated techniques now required.

The introduction of process analysis instruments poses new and complex problems for both the process and instrument industries, and it is only through the closest co-operation that satisfactory progress can be made. Effective quality control is a matter of extreme national importance. In many industries it also represents the key to higher productivity and reduced wastage, upon which, as we all know, our future prosperity depends.

Reed's new paper machine at Aylesford has more controls than any other in this country. But some problems of auto-control of papermaking remain unsolved; prominent among those being tackled are moisture and basis weight.

by **H. WIGMAN, B.Sc.**
Manager of the Paper Industries Division, Electroflo Meters Ltd.

Full Instrumentation aids papermaking

A PAPER MACHINE IS ONE OF THE LARGEST, AND YET MOST finely adjusted, pieces of mechanism found in any industry.* With its ancillaries it may occupy several acres and produce varying thicknesses of product from delicate tissue to building board. To operate such a machine 24 hours a day, six days a week, at speeds around 2000 ft/min, with a minimum of paper breaks, requires great engineering skill in machine design and manufacture, steadiness and perfect adjustment of the speed of distinct but interlocked parts, careful preparation of the paper stock, and the intelligent operation of the machine by men of experience aided by the best available instruments and control equipment.

STAR POINTS IN THE INSTRUMENTATION OF THE NEW AYLESFORD PAPER MACHINE

- ★ Central control room alongside machine
- ★ Six major subsidiary control panels
- ★ Graphic panels used throughout
- ★ Wide-range pulp proportioning system
- ★ Moisture measurement as first step towards end-point analysis
- ★ Instrumentation cost £75 000

At the Reed Paper Group's mill at Aylesford, Kent, a new machine (known as 'No 13') was commissioned in March this year and has been in continuous operation since then. It is designed to produce large quantities of consistent quality newsprint and mechanical printings. The machine contains more instrumentation than any other British paper machine, and in this article we briefly consider the essential part played by it by following the papermaking process from the wet to the dry end of the machine.

* A brief account of a paper machine was included in an article about control of drives on p 34 in the July issue. Readers who do not know anything about papermaking may like to refer to it.

Making paper involves:

1. Preparation of imported air-dry pulp to give a uniformly distributed suspension of fibres in water (known as stock).
2. Uniform distribution of the fibre suspension on an endless wire mesh (through which *backwater*, consisting of superfluous water and some fibres, drains).
3. Removal of surplus moisture by suction, pressure and heat treatment (carried out by press rolls and steam-heated dryer rolls).

STOCK PREPARATION

Counted batches of air-dry pulp are carried by a conveyor into one of two *hydrapulpers*, where they are mixed with measured quantities of backwater and additives. Initial pulping is carried out at 7 pc consistency (i.e. concentration of fibres) for about fifteen minutes, after which the pulp is diluted to 6 pc to permit pumping to a chest known as the *Soak chest*. Fig. 1 illustrates the above process graphically on the local control panel; the important local measurements, operations and alarms are duplicated on the left-hand section of the centralized graphic control panel (Fig. 2).

Close supervision of consistency throughout stock preparation is essential. Hence, batch operation of the hydrapulpers demands accurate control of the backwater supplied at the outset. Moreover, high continuous throughput requires that large measured quantities of backwater should be released to the hydrapulpers as soon as the latter have been discharged. These requirements are met by using 15 000-gallon measuring tanks, fed by diaphragm-type, positioner-operated valves, and emptied by large gate-type cylinder-operated valves; the valves respond sequentially to accurate fast-response on/off pneumatic level control signals. The on/off control units comprise an air-purged miniature pneumatic stack-type level transmitter, whose output feeds a similar design of controller; each of these instruments incorporates its own booster.

There are three desired measuring-tank levels: (a) the *filled position*, acting as the batching reference; (b) the *low position*, to which the level falls on release of the pulping batch; and (c) the *medium position*, to which the level falls on release of the dilution batch.

Levels (a), (b) and (c) are set by pneumatically loading the controllers. The desired levels are indicated separately, above the setting units and alongside a continuous level indicator, within the measuring tank symbol at the top of the local control panel (see Fig. 1). The instrument systems of interlocking controllers, pressure switches, relays, solenoid valves, auto/manual switches, pushbuttons etc are mounted in the local panels beside the hydrapulpers.

Filling of the measuring tanks to a fixed level (a) is automatic, and discharge cannot occur until this is reached (manual overriding controls are fitted). When the hydrapulper operator presses the pulping batch pushbutton, the filled measuring tank drops to its preset level (b), the control equipment causing the gate-type outlet valve to shut. Simultaneously the inlet diaphragm-type valves open automatically, and remain open until the level is restored to (a). After the operator decides the 7 pc stock has been pulped sufficiently, he presses the 'dilution batch' pushbutton and the level falls to position (c), diluting the stock to 6 pc; simultaneously the measuring tank level begins to return to position (a). By pushing the hydrapulper transfer pump 'start' button, the operator also opens a 16 in. gate-type cylinder-operated valve, the stock being delivered to the soak chests, which are large enough to provide material for about eight hours at maximum machine output.

The level indications (also recorded on the central control panel of Fig. 2) for the hydrapulpers and soak chests, are again provided by a small transmitter. The ancillary level alarms are conventional pressure-switch/electrical-relay devices operating pump and conveyor interlocks as well as the audible and visual alarm system which draws attention to abnormal conditions throughout the process. The operator controls the hydrapulpers from the local panels; only the level and other operating signals are transmitted to the central panel.

When filling the hydrapulpers, the operator, through pushbuttons, also controls the addition of china clay slurry and alum solution; the former by running a metering pump for a panel-indicated preset time and the latter by keeping a gravity-fed control valve open, until an integrating transmitting flowmeter signals that the batch is complete back to the preset panel-mounted indicator.

The next stage in the process is to reduce and control the consistency of the 6 pc pulp (known as *stuff*) transferred to six *hydrafiners*. Here the fibre bundles are split into individual fibres, enabling better water drainage and fibre bonding on the wire and under the presses at later stages in the process.

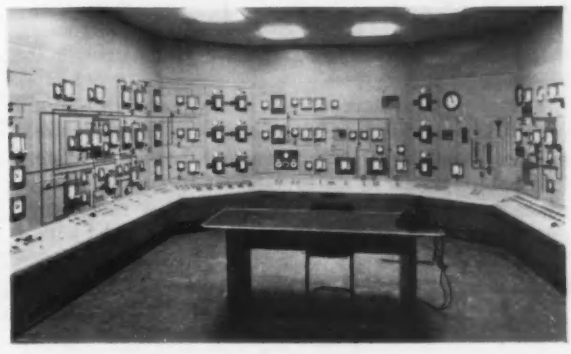
Consistency is a most important variable in papermaking, but a method of measuring it directly has not yet been developed, and an inferential system is used. Stuff consistency is directly related to what may be called *apparent viscosity*. Thus, the effective head of stuff required to pass a constant quantity of that stuff through a tube, being a measure of its viscosity, is also a measure of its consistency. Hence, by controlling the level in a stuff sampling box compartment receiving a constant flow of stuff, we can infer consistency control. The consistency-box level-measurement, which is rather 'noisy', results from a stuff sample taken from the transfer pump outlet. Control is effected by adding backwater into the pump inlet according to the demand of a wide-band proportional-plus-integral controller fed from an accurate, but suitably damped, level transmitter, the latter being appropriately purged.

Fig. 1 The groundwood hydrapulper control panel of the new Aylesford machine

The stuff enters the hydrafiners at a controlled consistency of about 5½ pc, and the consistency recording-controlling devices are mounted on the central control panel. The hydrafiners consist of conical plugs having surface bars, the plugs revolving in a conical shell whose inner surface carries corresponding bars. In operation, the plug is 'inched in', 'inched out' or 'run out' by pushbuttons on the central panel, so regulating the degree of rubbing and cutting of the fibres fed in at the small end of the conical shell. Input stuff pressure and flow, as well as the work done on the stuff in the hydrafiners, are important.

A special transmitter (Fig. 3), with its diaphragm vertical and flush with the input pipe (to minimize pulp blockage), transmits hydrafiner stuff pressure pneumatically to central panel receiver indicators; low flow is indicated as an alarm; and the work done is recorded by a wattmeter. A two-term pneumatic level recorder-controller, mounted on the main panel, operates the control valve passing 'hydrafined' stuff to storage chests known as *day chests*. The instrument system affords protection to each hydrafiner operation by withdrawing the relevant plug immediately low flow (high level

Fig. 2 The central control room with its well-designed graphic panels. Only the most important controls are included in this room



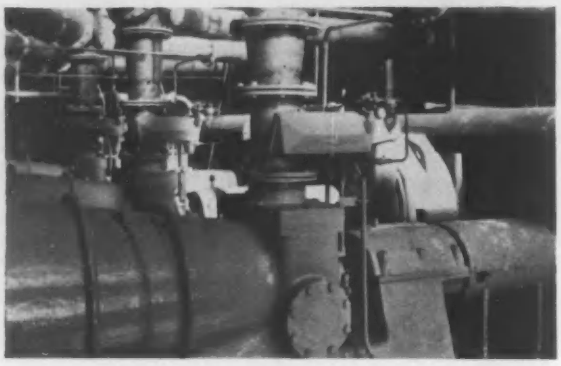


Fig. 3 Pulp pressure transmitters are mounted at the entries to the refiners

in day chests), low pressure or low level (in the soak chests) is detected; after a suitable time delay the supply pumps are also stopped. This mode of sequencing gives the best assurance that the plug will not 'collapse' into the shell, and so cause irreparable damage to the hydrafiner. There is, of course, a pressure reset system bypassing the low-pressure interlock for start-ups.

Two types of pulp, groundwood and sulphite, are used. Each of them requires different preparation, and this is reflected in the two parallel systems from the *backwater tank* to *day chest*.

Fig. 4 shows the pulp proportioning system which is used to ensure that the pulps are present in the desired quantities. Each stuff is delivered to its special area-type flowmeter at about 4 pc controlled consistency; a pneumatic ratio control system then passes the desired quantity of groundwood fibres according to the sulphite flow. The sulphite flow in turn is monitored by the level recorder-controller for the receiving *Jordan chest*, which also receives the repulped *broke* (trimmings and spoiled paper from the machine) for use again. A recent proportioning refinement is the addition of china clay into the Jordan chest, according to the total stuff flow signal, as transmitted by a stack-type pneumatic adding relay.

Instrument interlocks stop the hydrafiners and stuff pumps and shut all input control valves as soon as the Jordan chest high level is detected. This is done by an on/off level control installation similar to that used at the outset on the measuring tanks. After the blending operation there are two further stages of consistency recording-control, one during pumping of the mixed stuff between the Jordan and machine chests, and the other after the machine chest and before the final refining operation. There is also a level recorder-controller for the machine chest, together with associated high- and low-level alarm interlocks.

Each stuff chest and hydrapulper is equipped with agitators, to prevent fibres settling out; stop/start pushbuttons on the central panel operate these.

The machine has three refiners, whose function is to brush out still knotted bundles of fibres as well as to cut these to a more uniform length. The refiners, and the instrumentation for them, are similar to the hydrafiners. The refiners' output passes to a constant head box, the overflow recirculating through the machine chest. The head box is fitted with a 'stuff-gate' valve, operated pneumatically from either the local flow box control desk or the central panel. The flow of the —approximately 2¾ pc consistency—stuff is measured by a simple circular eccentric orifice plate connected to a suitably purged differential-pressure pneumatic transmitter. Stuff-gate position and flow through it are indicated on the local control desk, and indicated and recorded on the central panel.

2 THE WIRE PART

The metered quantity, at controlled consistency, of stuff leaving the head box makes it possible to produce paper of the desired weight and thickness. The regulated stuff is further diluted before the final screening and cleaning operations. It then passes into a pressurized flow box, where it is ejected through a narrow opening—called the *slice*—onto an endless moving bronze wire mesh. The 'diluted flow', which may be controlled from the local and central panels by inching buttons, is measured and indicated on the local flow box control desk: a comparison of the head and flow box flows on this desk (or from central panel recorders) enables the operator locally, or at the central panel, to ascertain and control the consistency of the stuff finally delivered to the flow box at approximately ½ pc consistency.

The controlled air pressure, provided by an air compressor, above the stuff in the flow box is recorded alongside the stuff temperature on a 2-pen recorder on the central panel. This temperature is measured by a linear gas-filled bulb pneumatic transmitter system. A pH recorder-controller regulates the flow of alum solution depending upon the pH-value measured—before Selectifier screens—by a continuous-flow stainless-steel electrode sampling system. This system generates a pneumatic signal proportional to the pH-value, and the instruments adjust the alum injection into the inlet of the fan pump accordingly, whence the pH-controlled stuff accepted by the Selectifiers enters the pressurized flow box. Pneumatic adjustment of the slice from the flow box control desk gives control over the stuff speed onto the wire.

3 REMOVING WATER

The wire passes round a free breast roll at the 'flow box end', and a driving couch roll at the 'paper end'. The top of the wire carrying the pulp suspension is supported by flat wooden boxes, and a *dandy roll*, for watermarking, rides on the wire above the boxes. The emergent flow box pulp stream containing 99·5 pc water is confined for a short distance by deckle strips on either side of the wire, and during this confinement much of the surplus water drains into the wire pit, whence it is recirculated through a large backwater surge tank.

A central-panel level recorder-controller for the flat boxes' seal pit enables suction to be applied in these boxes, and this suction, transmitted pneumatically to a central recorder, draws more water out of the still very wet stuff. Raise/lower pushbuttons give control of the dandy roll, from the local couch desk, after which further water is removed by suction in the large driving couch roll, the suction being once again transmitted pneumatically to central recorders. At the couch roll the fibre content of the wet sheet is still not above 20 pc, and the considerable quantity of water drained and sucked off is returned subsequently to the process via a large surge tank. From this tank central panel-mounted pressure recorder-controllers assure a sufficiency of backwater for the preparation and consistency control of the stuff. However, the paper web is strong enough at the couch roll to be transferred, by a vacuum pick-up system, through three presses fitted with lower suction rolls.

The control-room operator can make independent front-and-back press load adjustments, which are recorded centrally. However, the decision to load or quickly lift the relevant top press roll depends upon the operation of the corresponding air selector switch on the nearby local press control desk. Various instrument interlocks govern the operation of the pick-up roll in relation to its own and the flat and couch box vacuums, the important features being controllable from a local desk and signalled back to the central panel. Other recordings made centrally up to this stage in the process include suction in the pick-up and press suction rolls, and levels in the seal pits for the couch and presses.

A feature of the machine is an elaborate deluge shower and paper conveyor system: fresh water is selected initially and replaced automatically by backwater, if available. Several instrument interlocks initiate, or interrupt the operation, depending upon flow box pressure, photoelectric detection of a paper break and pick-up suction. The interlocks may be overridden manually from adjacent control desks, and the instrumentation is designed to assist in the rapid disposal of large piles of wet paper, which might otherwise accumulate quickly and cause damage.

From the presses the paper web enters the steam-heated drying section at about 60 pc moisture content. On leaving the drying section the sheet will have become in 'moisture equilibrium' with the atsmosphere. The dryer has fifty-nine steam-heated cylinders, and the paper received from the smoothing press is held by felts against the cylinder surfaces. The steam supplied comes at low-pressure from a pass-out turbine, and simple proportional recording-controllers, mounted on a separate graphic panel, adjust the steam supply to the separate section. An automatic paper-break reset device prevents cylinder overheating, the amount by which the desired pressure is reduced being adjustable from a panel-mounted pneumatic indicating ratio relay. Other dry-end instrumentation includes electropneumatic recording and integration of the various steam and condensate flows; and indication and control of condensate tank levels and of the temperature of the condensate leaving the heat exchanger.

A special moisture meter is fitted between the machine calender and reel to give longitudinal and transverse sheet moisture profiles, and tests on adjusting the dryer steam control system from the moisture measurement are in progress. Such meters are likely to be increasingly fitted in new paper machines. They represent a development towards end-point analysis in paper control.

Separate local control desks are employed for the machine calender and reel, beneath which, running the full width of the paper machine, the broke is repulped in a special pulper. Interlocking level and consistency recording-controllers supervise the broke pulper operation, and pressure and level recorder-controllers transfer broke to the couch pit. From this pit a further level recorder-controller regulates the output, which eventually reappears in the Jordan chest.

4 MISCELLANEOUS

The water system has necessarily been briefly described. In addition to the incidental comments above we note the use of centralized level recorder-controllers for the clean fibre, clean water, clarified water and save-all vessels, and that dual control systems in two of these applications are reflected in the use of special 3-pen recorders. A pressure recorder-controller supplies clean water to the seal glands.

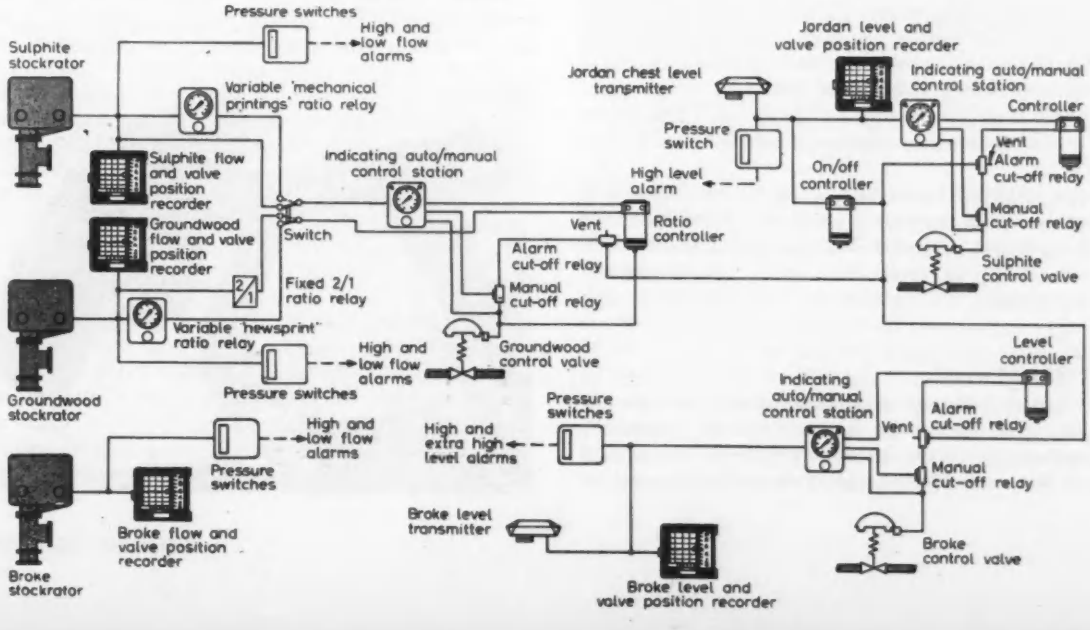
Three drainage systems are used on the machine, and these are for clean water, clean fibre and dirty water. The dirty water flow passes through a large conical entrance venturi, where its measurement by a purged differential pressure device provides the means for centrally recording and integrating its value. The clean fibre drains receive fibre-laden overflows from various chests, etc, and discharge into the level-controlled clean fibre sump. The clean fibre is then pumped into the recovery systems, and the effluent from the latter, this time measured by an eccentric circular orifice plate, is recorded and integrated alongside the dirty water flow.

Total fresh-water flow measurement is most important and this, too, is recorded and integrated on the central panel. The groundwood, sulphite and broke flows are also recorded and integrated on the central panel, and analysis of pulp, water, steam and effluent usage provide necessary information for assessment of the machine performance.

Acknowledgments

The author wishes to thank the Directors of Electrofio Meters Co and Albert E. Reed & Co for allowing this article to be published, and particularly wishes to acknowledge the invaluable assistance rendered by Mr R. C. Gardner, Chief Instrument Engineer of the Aylesford Paper Mills, in its preparation.

Fig. 4 Schematic of pulp proportioning system



CONTROL ON SHOW

by **D. W. ALLEN**
Guided Weapons Department, Royal Aircraft Establishment, Farnborough

Farnborough — S.B.A.C. Exhibition

FOR THE CONTROL ENGINEER VISITING THE S.B.A.C. EXHIBITION AT Farnborough this year, one of the most interesting aspects was the diversity of the guided weapons control systems displayed. With only ten missiles on view no less than five different guidance systems and five different arrangements of control surfaces were to be seen.

Air-air and surface-air weapons

Beam riders were represented by the Fairey Fireflash air-to-air training missile. This weapon does not use 'lock-follow' radar and so relies on the skill of the pilot of the launching aircraft in holding his fixed beam on the target by suitable manoeuvres of his aeroplane. It is of cruciform construction with what, a few years ago, would have been called conventional all-moving-tail controls. This year there were also examples of flap, jet and nose control systems.

Three *semi-active homing* missiles were on show: the Short-Elliott General Purpose Vehicle had its homing head opened up for inspection, while the English Electric Thunderbird and the Bristol Bloodhound had theirs discreetly covered by radomes. Two of these three, the GPV and the Thunderbird, are tail-controlled cruciform missiles, while the Bloodhound is of the aeroplane-like 'twist and steer' configuration and is controlled by moving wings. When correcting its flight path, this missile must first roll into a plane at right angles to the error direction, since it can manoeuvre only in a plane normal to its wings.

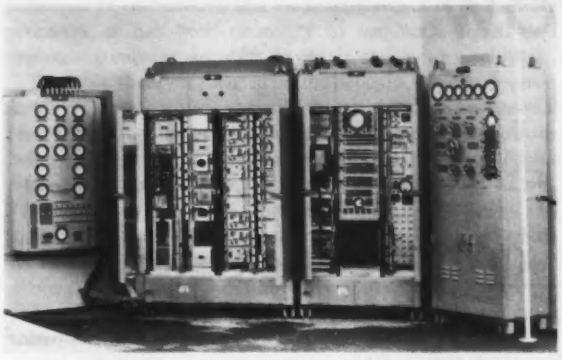
The de Havilland Firestreak was the one representative of the *passive homing guidance* system; it is fitted with a de Havilland-designed infra-red homing head and is a tail-controlled cruciform missile. No details of its control and guidance systems were available.

Anti-tank missiles

Until recently the *visual command guidance* system was neglected in British missiles, but now both the Vickers 891 and the Pye anti-tank missiles employ it; the public could see them at this year's Farnborough show for the first time. A command guided missile is steered towards its target by a controller operating a joystick in order to hold the missile flares on a line between his eye and the target. This use of a human guidance system results in a very simple missile which is ideally suited to infantry anti-tank use, where the missile must be small enough to be carried by one man and instantly ready for firing. Where the main guidance loop is closed by a human operator it is imperative that system lags are minimized if stable control is to be achieved; in particular the incidence lag of the tail-controlled missile (i.e. the lag between the control surface movement and the build-up of lateral acceleration) should be as short as possible, and it is intriguing to see how this problem has been tackled by the designers of anti-tank missiles.

The Vickers 891 has flaps arranged to produce lift directly on the main wings. The Pye missile has no tail surfaces and the wings are obviously fixed: so it can be assumed that it is controlled by movement of the main propulsion jet. The

Joystick unit for the Vickers 891 anti-tank missile. The firing trigger is on the front handgrip, and the thumb-operated joystick is the stirrup-like device between the rear handgrip and the face-pad. A times-six magnification monocular is fitted on top of the unit, while the transistorized control shaping networks are enclosed within the body



The Sperry system checker for the Seaslug missile. The automatic switching unit is on the left of the large cabinet with the recording equipment in the right-hand centre cabinet.

relative economics of these approaches are difficult to assess, for no details were available at Farnborough of the actuators used in the Pye missile, although those used in the Vickers weapon were commendably small.

Very little information has been released on the control or autopilot systems used in the various missiles, and it was therefore particularly interesting to see the component parts of the Vickers 891, complete and 'exploded', laid out for all to examine. The remarkably small two-gyro unit is mounted behind the warhead and immediately in front of the motor, while the annular actuator assembly is fitted around the motor blast tube. The autopilot, mounted on a printed-circuit board and encapsulated, forms the external connexion between the gyro unit and the actuator. Another item of interest was the use, by both Pye and Vickers, of thumb-operated joysticks for control of the missile. These differed in detail, that of Vickers looking for all the world like a small machine gun with an optical sight mounted along the top and a firing trigger on the front handgrip, while Pye's was a one-handed unit used in conjunction with a periscope sight.

Seaslug

Some idea of the complexity of a modern fully automatic weapons system could be gathered from the Sperry Gyroscope Co's shipboard checking system for Seaslug. This facility is intended for the routine checking of the missile control system. The components are plugged in and the voltages and currents at various points measured for appropriately switched inputs. The switching operations are carried out automatically, each sequence being initiated by a manual press-button. The testing can be carried out in any way: but it is usual, when checking the whole missile, to start at the fins and work back to the guidance system. The checker, which is housed in several large cabinets, has its own built-in standards and displays the errors between the checked unit and the standard on an oscilloscope or a pen recorder. Fairey Aviation showed a somewhat similar pre-flight checker for the Fireflash.

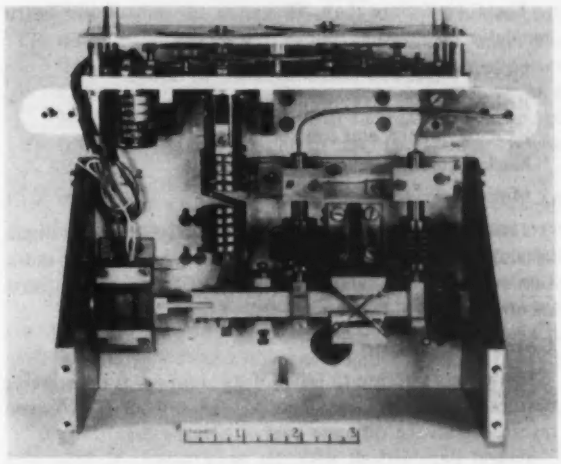
Liquid chassis cooling

Wherever a large amount of electronic equipment has to be packed into a small space, cooling becomes a problem. On the Ministry of Supply stand the Royal Radar Establishment exhibited a method for cooling an electronic chassis. The chassis itself, with all the heat producing components mounted directly on it, is formed of a pressure-bonded aluminium ducted sheet. The coolant is passed through the ducts and can, if necessary, be routed into similar ducted valve cans. Maximum dissipation was quoted as 1 W/in^2.

Servo-operated aircraft instruments

On the aircraft side servos were much in evidence, two particularly interesting systems being shown by Smiths Aircraft Instruments and by Kelvin and Hughes. Both are used to improve the accuracy and response of pressure-operated aircraft instruments. With modern high-performance aircraft, lags in sensitive pressure instruments such as the altimeter are no longer tolerable, and so Smiths, in collaboration with the Ministry of Supply, decided to replace the somewhat cumbersome mechanical gear train, linking capsule and pointer, with a high-performance a.c. servo. Movements of the pressure-sensitive capsule with changes of barometric height alter the position of an 'E' and 'I' type inductive pick-off. This unbalances the servo which drives the indicator mechanism until a new null position is reached. The capsule assembly has, therefore, only to move a light pick-off, and a much greater sensitivity can be obtained with almost negligible system lag.

The Kelvin and Hughes pressure transducer goes a step further and replaces the conventional measurement of capsule movement by a direct measurement of force. The force balance unit, as its name implies, balances this force by means of a servo-operated spring. Servo shaft position is therefore directly proportional to pressure. For use as an altimeter the output is transformed mechanically, by means of a cam, from pressure to height. This output is then corrected for position



The Kelvin and Hughes force-balance pressure transducer. The capsules are on either side of the crossed spring pivot and the force feedback spring can be seen directly below the left indicator dial and gear train.

error, using a computing circuit fed from a transmitting machmeter. Two capsules are provided in the unit so that it may be used as an airspeed indicator, or indeed any fundamentally pressure or differential-pressure instrument. With such an arrangement accuracy is directly related to the performance of the spring, which must be unaffected by changes of environment. The one at present used was specially designed by Kelvin and Hughes, in co-operation with spring manufacturers, for this application: it is made of Invar.

Altogether the Farnborough show was most instructive, with several new applications of control engineering highlighting a year of steady development.

CONTROL ON SHOW

Geneva—
atoms for peace conference

by K. W. CUNNINGHAM, B.Sc., A.M.Brit.I.R.E., A.Inst.P.
Chief Engineer, Plessey Nucleonics Ltd

THE SECOND WORLD CONFERENCE ON THE PEACEFUL USES OF Atomic Energy took place in Geneva on a much greater scale than its predecesssor three years ago. A vast amount of scientific work was published in more than 2500 technical papers, supported by a scientific exhibition sponsored by the participating governments and a commercial exhibition where private firms displayed their products.

The technical papers were grouped into about eighty different sessions and roughly a quarter were presented verbally in the various conference rooms in the Palais des Nations. To accommodate the scientific exhibition, a special building was erected in the grounds of the Palais des Nations, whilst the commercial exhibition was located elsewhere in Geneva at the Palais des Expositions.

There were more than 200 papers on control and instrumentation grouped as follows:

Special topics and instrumentation in fusion

Reactor theory and computing methods

Reactor kinetics and control

Nuclear instrumentation and technique

Mining aspects and instrumentation

This classification is very approximate since, for example, several papers on isotopes and the biological effects of radiation contained substantial accounts of the associated instrumentation.

Controlled fusion

It was very striking to learn of the amount of effort being devoted (notably by Great Britain, USA and USSR) to fusion research, with the ultimate goal of cheap energy.

Several papers dealt with the basic theory of controlled fusion and detailed accounts were given of experience with individual machines such as Zeta, Sceptre, Alpha, etc.

In all these machines, a light gas (e.g. deuterium) at low pressure is heated to a high temperature. It has been forecast that fusion will become self-sustaining in a mixture of deuterium and tritium if the temperature can be raised to the region of 50 - 100 $\times$ 10^6 deg C. At still higher temperatures, a reaction known as the deuteron-deuteron reaction should be possible and this has several attractive features. Temperatures in the region of 5 $\times$ 10^6 deg have been claimed for individual machines, and many difficulties have been encountered in maintaining a stable plasma.*

The problem of measuring temperature in this region was discussed in some papers. One method used quite widely is based upon the Doppler broadening of the spectral lines from the light emitted by the hot plasma. Above one million degrees, hydrogen ceases to retain its electrons in a bound state. In order to obtain a line spectrum above this temperature, it is necessary to add a small quantity of some impurity. By this means a line spectrum in the ultra-violet region can be observed using a quartz prism spectrograph. As the hot ions in the plasma vibrate in all directions, some towards the spectrograph and some away at the instant when they emit a photon, the observed wavelength is shortened or lengthened in accordance with the well-known Doppler principle. This causes the observed spectral line to broaden, and as the temperature is proportional to the velocity squared, the degree of broadening is proportional to the square root of the temperature. Many factors render this type of measurement uncertain and several other methods are employed to corroborate the results. For example temperature can be related to the intensity of line (or continuous) spectra, neutron yield, electrical conductivity, etc, and in practice several methods are employed simultaneously.

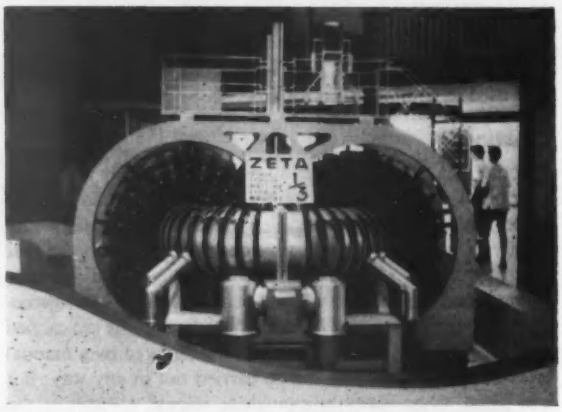


Fig. 1 A model of Britain's Zeta was on show in the scientific exhibition

Various forecasts indicate that another ten years may be necessary before fusion becomes a commercial proposition, and that the power producing fusion machines may well be of similar size to present-day reactors.

Reactor theory and computing methods

More than sixty papers dealt with this subject, of which twelve were presented verbally. The basic theory of reactor design is now fairly well understood but, because of the

* A plasma is a very hot gas in which the electrons are no longer bound to the individual atoms, but move freely throughout the gas. In this state the gas consists of a mixture of positive ions and free electrons and is electrically neutral.

multitude of calculations and the complexity of many nuclear processes, it has been necessary to use both digital and analogue computers in order to obtain satisfactory solutions.

The basic theory is focused on the behaviour of the neutron in all the possible processes which can occur in and near a reactor core, i.e. the neutron transport theory. Since neutrons behave differently at different energies, it has been found necessary to consider the neutrons in different energy bands. This has led to what are known as one-group, two-group and multi-group theories. The greater the number of groups which are embodied in an analysis, the greater the accuracy obtained —but also the greater the complexity of the calculation.

The papers in this section were concerned with this basic theory and the adaptation of the analyses for solution by digital computers.

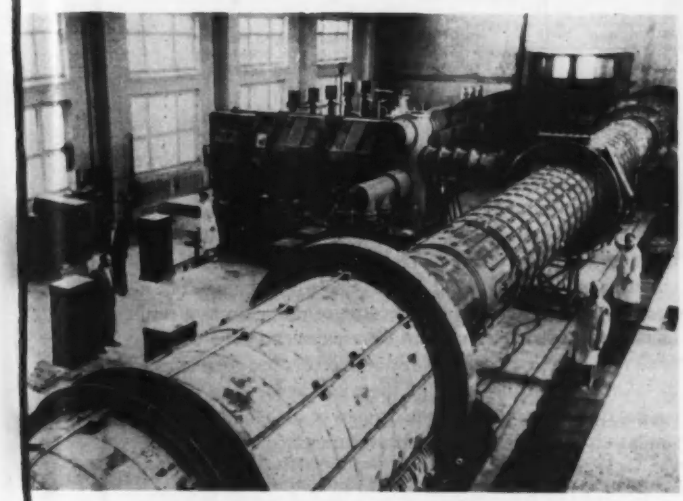


Fig. 2 The Russians showed a model of OGRA, the large mirror-type thermonuclear machine, here seen under construction in Moscow

Reactor kinetics and control

In this section, several papers were concerned with the general behaviour of a reactor under steady-state and dynamic operating conditions. They included analyses for particular types of reactor (e.g. boiling water, heavy water moderated and gas-cooled) in which attempts have been made to optimize the design to obtain flexible control with inherently safe characteristics. Most of this work was centred on the exploitation of the negative temperature coefficient of reactivity to prevent the possibility of an excess power transient, even if the normal control system should be misused.

Analogue computers and special purpose simulators have been used extensively in this connexion. For example, one paper described a computer for the evaluation of the build-up of xenon poisoning. Other simulators have been used extensively for the training of reactor operating staff, an example of this being the Elliott Type ND181, which was on show in the commercial exhibition.

Several papers dealt with general control philosophy.

The general pattern of such control systems has emerged as the result of several important safety requirements, the basic properties of the reactor and the available measuring and control devices. A typical power reactor may possess as many as eleven measuring and control channels, with functions as follows:

a. *Start-up channel.* This is usually a pulse counting system. It is now common practice to insert one or more neutron sources in the core in order to reduce the ratio of neutron flux between the shut-down condition and full power operation.

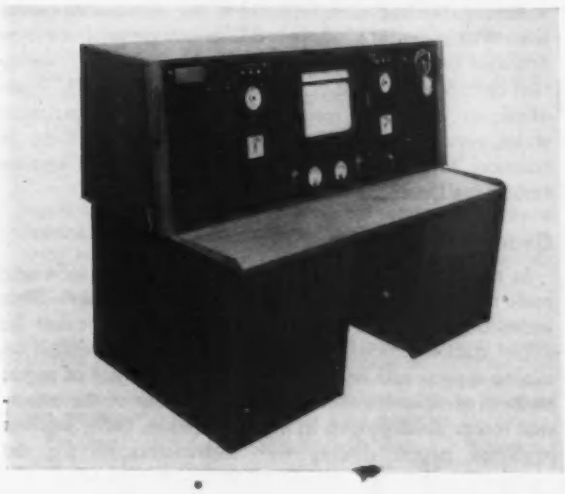
b. *Logarithmic power channel.* This is usually a d.c. system using an ionization chamber. The small current from this detector is amplified and fed to a logarithmic element. Diodes and pentodes have been used as the logarithmic element and have provided a logarithmic output over size to seven decades. This output is usually displayed on a recorder, ranging from full power down to six or seven decades below this level.

c. *Period channels.* If the logarithmic output is differentiated a signal is obtained which is related to the reactor period, or doubling time (i.e. a measure of reactor stability). For example, if a reactor is stable (at any power level) it possesses an infinite doubling time; if the power is increasing, and doubles its value in ten seconds, then this channel will indicate a doubling time of ten seconds. This can conveniently be arranged on a meter scale with preset safety trips to prevent rapid rises in power. For period information below the range of the logarithmic power channel, a pulse counting technique can be used. This can take the form of a ratemeter system, but because of the poor statistical accuracy at low powers, the information has a limited usefulness.

d. *Linear power channel.* This is usually a d.c. system using an ionization chamber and a linear d.c. amplifier feeding a recorder calibrated in output power. This channel is the principal control channel when operating at, or near, full power. For convenience of operation in this range, it is usual to provide an indication between the actual power and the desired power. This arrangement is known as a backed-off or deviation channel and may be arranged to operate independently from the main linear power channel.

e. *Shut-down channels.* These are basically backed-off linear power channels using ion chambers and some form of differential d.c. amplifier. A preset reference power level is compared with the measured power. As soon as the measured value exceeds the reference, a sensitive trip circuit operates to either release the shut-off rods, or to inject a controlled amount of negative reactivity in order

Fig. 3 The Elliott simulator Type ND181 was designed for training reactor staff



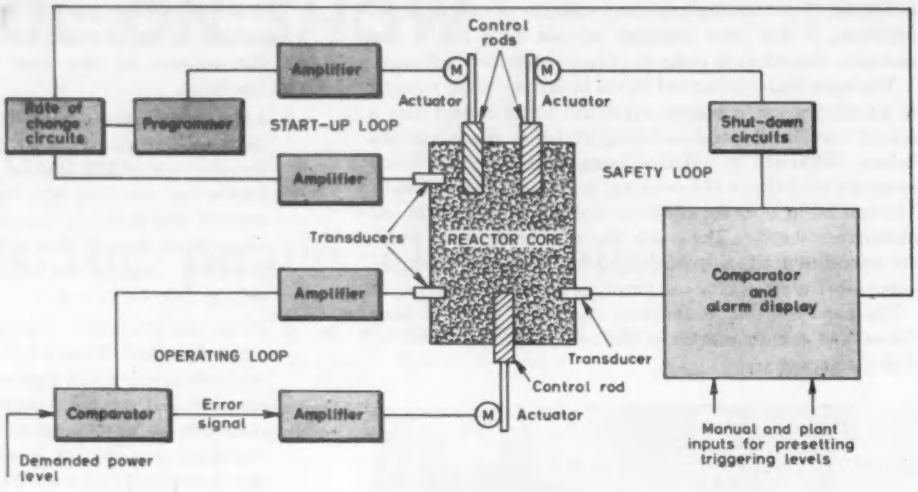


Fig. 4 This schematic illustrates a typical arrangement of a control system suitable for both experimental and power reactors

to safeguard the reactor. One essential feature of these channels is that they must fail safe, and several critical studies have been made of the various possible components in these channels, to obtain the most reliable system. To avoid unnecessary shut-downs due to component failures and interference from other apparatus, it has become usual to have three shut-down channels, arranged in such a fashion that if only one channel trips, it will initiate a warning; shut-down action will not occur unless two or three channels trip.

Papers dealt with the relative merits of various combinations of measuring channels, the location of the detectors with respect to the reactor core, the desirability of overlapping channels and other features affecting the general ease with which control can be reliably implemented. One paper considered the problem of linking a power producing reactor to the electrical generating plant. This introduces problems concerning efficient overall generation of electricity to meet full base load and reduced load demands. The characteristics of reactor, heat transfer system, steam raising unit and turbo-alternators were discussed, together with the requirements for automatic control to maintain a constant frequency of the electrical output.

The extent to which the theory and practice of reactor control has become standardized could be observed in the wide range of equipment displayed at the commercial exhibition. Many versions of the various components are now available i.e. fission counters, proportional counters, ionization chambers, linear d.c. amplifiers, pulse amplifiers, logarithmic d.c. amplifiers, recorders with linear and logarithmic scales, period meters, control-rod drive mechanisms, etc. In addition, several firms exhibited complete control systems embodying the above components.

General instrumentation

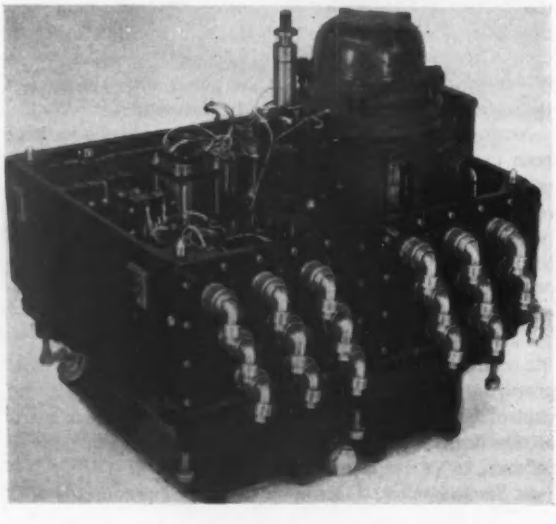
In the session on nuclear instrumentation and technique more recent neutron detection devices were discussed. These included gaseous and organic scintillation detectors and the use of nuclear emulsions. Several papers in the session on mining aspects and instrumentation gave a review of recent methods of radioactive survey and descriptions of the associated recent developments in instrumentation. Other sessions contained papers dealing with instrumentation for the measurement of radioactive effluents from nuclear power stations, radiation hazards in uranium mines and measurements concerned with dosimetry and health physics.

In considering reactor safety, delegates described the effects of three major accidents. Two reactors were put out of commission for a year and one has been written off, but no one was hurt or received an overdose of radiation as a result of the accidents. A significant improvement in the containment and instrumentation of future reactors has been effected by taking note of the details of these accidents. Most authorities are now quite confident that in view of such improvements, similar accidents will not arise in future.

Conclusion

In summing up the conference, Sir John Cockcroft said that it had been most successful. It exemplified the proper way in which scientists of all countries could exchange information. He did feel, however, that the conference was too large. With such a vast assembly of technical data and exhibits, it was almost impossible to assimilate properly all that one would wish, in the time available.

Fig. 5 The Hobson master gearbox for coarse control of rods, of the type used with the Dido and Pluto reactors



DATA SHEET—3

HOW TO APPLY PRESSURE CHARACTERISTICS OF LINEAR VALVES—1

by **P. D. BOYER, B.Sc.**
English Electric Co, Luton Airport

This is the first of a series of four Data Sheets on the pressure-deflexion-flow relationship for linear hydraulic valves and deals with the closed-centre or zero-lapped valve. It includes a general introduction to the series and some background information on flow through hydaulic valves

Introduction

Field plots of flow versus load pressure for various values of valve deflexion have been published in the literature on hydraulic control, notably by Blackburn (*Trans. Amer. Soc. Mech. Engrs., Vols. 74 and 75, No. 6*). Four Data Sheets, of which this is the first, will present this information in a less familiar way, showing the output pressure versus valve deflexion with flow as the third sampled variable.

This approach finds an application in the study of friction problems in hydraulic servos. Stiction is very often the principal source of error in the output, once the loop has been closed, and prohibits the employment of the small gain margin which linear theory would suggest is practicable. The pressure characteristics also provide a useful test for servovalves. Their use in determination of reset error, null shift, evaluation of waveforms, lap and leakage characteristics will be considered.

The Data Sheets deal with both three- and four-way valves, each covering one of four sub-classes of valves: zero-lapped; fully under-lapped; partially under-lapped; and partially over-lapped. The graph for zero-lapped valves appears overleaf. These graphs apply only to linear valves, or more exactly to valves with flow proportional to deflexion at constant load pressure, but such a characteristic can be obtained with great accuracy; many high-performance valves having one are now in military service. Servos using them are usually designed for an output load pressure swing which is small relative to the stall pressure (i.e. the pressure drop across the motor when it is held externally and the valve fully deflected). In these circumstances, even if the pressure swings up to as much as 25 pc of the available stall pressure, linearity is barely affected by load changes. This is perhaps at variance with popular belief.

Oil flow through valves with sharp edges

The oil flow through a valve orifice is turbulent and can be calculated from Bernoulli's equation

$$P + \tfrac{1}{2}\rho v^2 = \text{constant} \qquad \ldots (1)$$

We treat ρ as constant.

The constant in equation (1) is the upstream pressure P_s, giving

$$v = \sqrt{\left[\frac{2(P_s - P)}{\rho}\right]} \qquad \ldots (2)$$

We have also

$$Q = Av \qquad \ldots (3)$$

Where the area A is that of an orifice and P is the static pressure in the chamber on its downstream side, it is necessary to allow for stream contraction. As the stream contracts to pass through the orifice it acquires radial momentum, so that the tendency to contract persists, even downstream of the orifice. A minimum cross-section is finally reached, the vena contracta, and only at this point is the stream in equilibrium with its surroundings and the velocity given by equation (2) achieved. It will expand again further downstream when forced to slow down.

If the *contraction coefficient* C_q is defined by

$$C_q = \frac{\text{Area of the vena contracta}}{\text{Area of the orifice}}$$

then

$$Q = C_q Av$$

This equation is more accurately written

$$Q = C_d Av$$

where C_d is an overall discharge coefficient taking account of energy loss due to friction. It is generally accepted that C_q and C_d differ by less than 1 pc however and the terms have therefore tended to be used as if synonymous. To conform with custom C_q is used here. It can be calculated with accuracy for the simpler configurations.

Thus

$$Q = C_q A\sqrt{\left[\frac{2 \times (\text{Pressure drop})}{\rho}\right]}$$

the equation of flow.

Variation of the contraction coefficient

The discharge contraction coefficient C_q is applicable to turbulent flow, and when this is fully developed, C_q is independent of pressure drop. However, if the geometrical form of the orifice varies with opening, C_q will also vary.

Servovalves are commonly of the spool or piston type, in which the piston covers up a rectangular or round port in the wall of the sleeve or cylinder. Discharge coefficient variation is very marked with the round port, C increasing as more of the port is uncovered. The variation is less serious with a rectangular port and can be negligible if the port is extended around the full circumference of the wall. Then the flow is nearly two-dimensional, and so the variation in discharge coefficient is only two-dimensional and therefore minimized.

Thus the equation

$$Q = C_q A\sqrt{\left(\frac{2\Delta P}{\rho}\right)} \quad \text{or} \quad C_q w X\sqrt{\left(\frac{2\Delta P}{\rho}\right)}$$

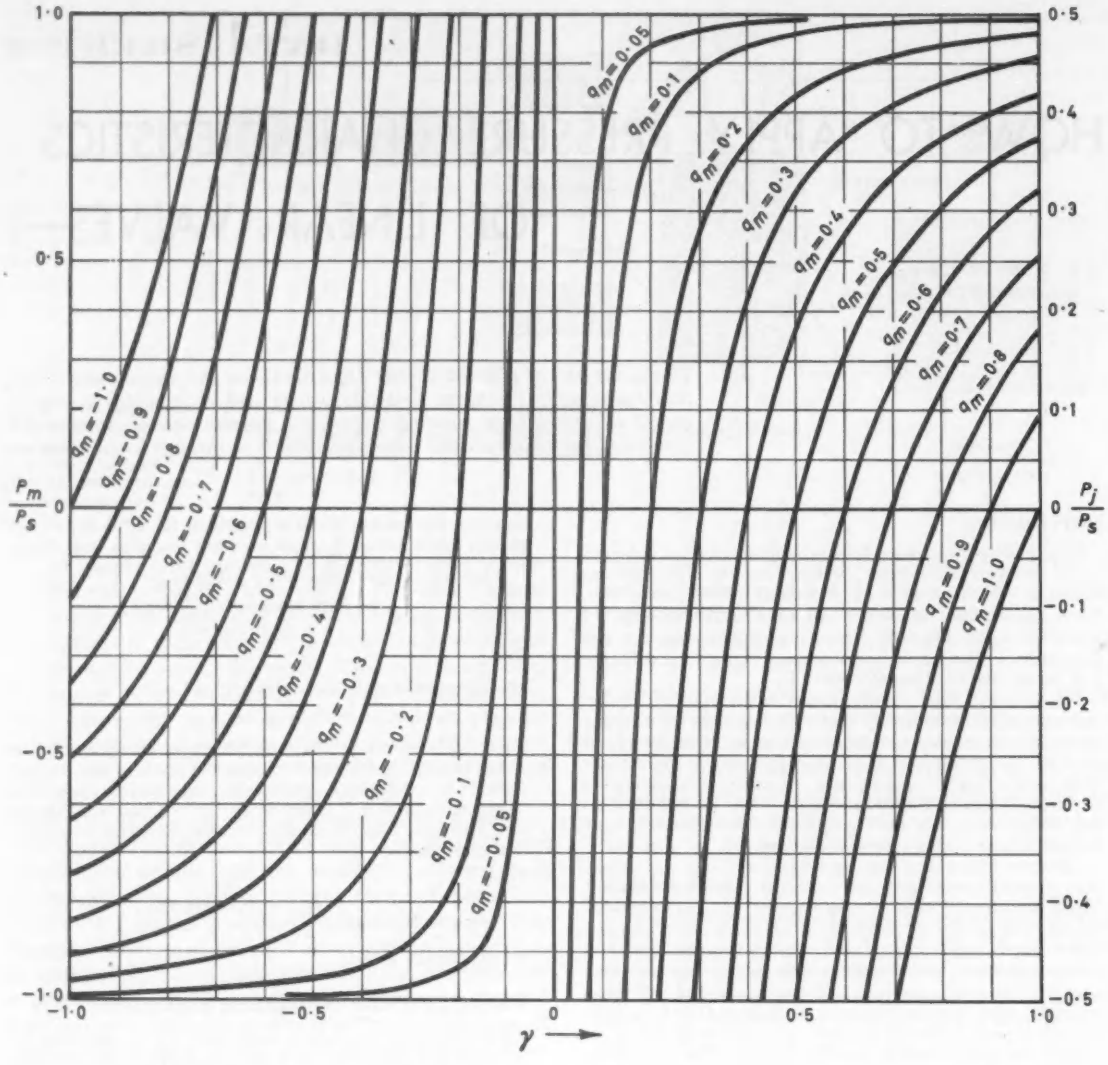
where w is the total port width and X the valve deflexion from nominal zero, can be very accurately conformed to, and is in fact fairly well followed by numerous high-performance servovalves.

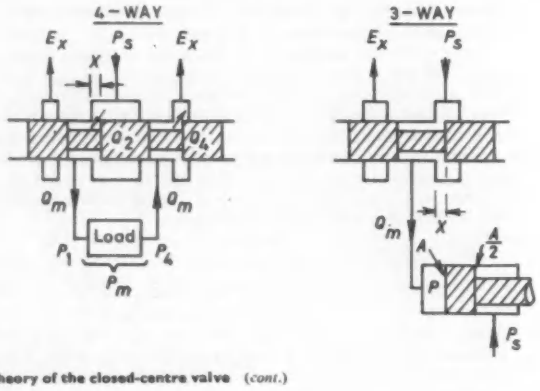
Theory of the closed-centre or zero-lapped valve

Referring to the diagrams overleaf, the valve is assumed linear to the extent that its flow at set port pressures (and therefore at a given load) is proportional to deflexion. For greater generality the flow into the jack Q_m is divided by a reference value to give the non-dimensional value q_m. The reference value is Q_{max}, the no-load flow into the jack when the valve deflexion X is a maximum.

Put $Q_{max} = C_q w X_{max}\sqrt{(P_s/\rho)}$; $q_m = Q_m/Q_{max}$; $\gamma = X/X_{max}$

(continued overleaf)





4-WAY $p = \frac{P_m}{P_s} = \pm\left(1 - \frac{q_m^2}{\gamma^2}\right)$ $\gamma > 0$ $\gamma < 0$

3-WAY $p = \frac{2P_j}{P_s} = \pm\left(1 - \frac{q_m^2}{\gamma^2}\right)$ $\gamma > 0$ $\gamma < 0$

SLOPE $\left(\frac{\delta p}{\delta \gamma}\right)_q = \frac{\pm 2(1 \pm p)^{\frac{3}{2}}}{q_m}$ $q_m > 0$ $q_m < 0$

$= \pm\frac{2q_m^2}{\gamma^3}$ $\gamma > 0$ $\gamma < 0$

On the γ axis, $\frac{\delta p}{\delta y} = \pm\frac{2}{q_m}$ $q_m > 0$ $q_m < 0$

Theory of the closed-centre valve (*cont.*)

(*a*) *The three-way type*

Put $P_j = P - \frac{1}{2}P_s$ and $2P_j/P_s = p$

Then

$$Q_m = \begin{cases} C_q w X \sqrt{(2P/\rho)} & \text{for } X < 0 \\ C_q w X \sqrt{[2(P_s - P)/\rho]} & \text{for } X > 0 \end{cases}$$

Therefore $q_m = \gamma\sqrt{(1 \pm p)}$ for $X \lesseqgtr 0$

and $p = \pm\left(1 - \frac{q_m^2}{\gamma^2}\right)$ for $X \gtreqless 0$

(*b*) *The four-way type*

Put $P_m = P_1 - P_4$ and $P_m/P_s = p$

Then for $X > 0$

$$Q_2 = Q_m = Q_4$$

i.e. $C_q w X \sqrt{(2P_2/\rho)} = Q_m = C_q w X \sqrt{(2P_4/\rho)}$

Hence $P_2 = P_4 = P_s - P_1$

Therefore $1 - p = 2P_2/P_s$

and $q_m = \gamma\sqrt{(1 - p)}$

Similarly for $X < 0$ $q_m = \gamma\sqrt{(1 + p)}$

Thus $p = \pm\left(1 - \frac{q_m^2}{\gamma^2}\right)$ for $X \gtreqless 0$

Transistors for ultra high frequencies demand automatically controlled production—say Semiconductors Ltd

Making transistors— by autocontrolled methods

by **DR JAMES REEKIE, F.R.S.E., F.INST.P., A.M.I.E.E.**
Semiconductors Ltd, Cheney Manor, Swindon

UNTIL RECENTLY TRANSISTORS WERE MANUFACTURED IN THIS country largely by hand. Critical stages in the processing—stages at which intrinsic characteristics of the transistor are determined—had generally been controlled only by programmed temperature schedules. Depending upon the type of transistor, this control may have been exercised during the initial growing of the semiconductor crystal or during a subsequent alloying or diffusion process. Variants of these basic processes are also used, but all such methods produce *junctions* in the semiconducting material, and on the presence of these the action of the transistor ultimately depends.

It is generally appreciated that significant dimensions of present-day transistors are in the region of a few thousandths of an inch. Clearly therefore the operating characteristics of transistors have wide tolerances unless dimensional controls to well within a ten-thousandth of an inch are exercised. This is difficult and may indeed be regarded as the basic reason for the low efficiency of conventional transistor manufacture at the present time. With the possible exception of particular applications of the diffusion process, one can scarcely expect that production depending upon temperature control alone will be capable of appreciable improvement in this respect.

Nevertheless, the so-called *alloyed, grown junction, diffused base*, and related techniques of transistor manufacture have achieved a commercial success which is only now beginning to be seriously challenged. This challenge arises from a number of causes, both technical and commercial, but so long as relatively low operating frequencies and a rather wide spread of characteristics can be tolerated the techniques are satisfactory. Today, however, commercial transistors capable of operating in circuits at frequencies of several hundred megacycles per second are greatly needed, and this, coupled with close tolerance on the inherent characteristics, necessitates basically new control processes in manufacture. Not less important is the economic aspect; the ability to maintain close control on characteristics automatically results in higher 'yields' of desired transistor types, with consequent reduction of the unit price.

For many purposes one may consider the most important single characteristic in a transistor to be the *base width*. This is, effectively, the internal path (of the order of a few ten-thousandths of an inch) in the semiconductor through which charge carriers must drift under the action of the operating voltages, and is the most critical dimension in the manufacturing process. Close control of base width permits reproducible high-frequency characteristics to be consistently achieved.

Controlled electrochemical etching

Over the past four years an electrochemical production technique has been developed by the Philco Corporation in the United States, and recently installed in the Semiconductors Ltd factory at Swindon in England, for production of germanium transistors. This process is largely automatic and involves certain unique control features which for the first time permit the requisite parameters to be developed in the transistor *during its manufacture*. The sequence of events in one critical stage of processing is illustrated diagrammatically in Fig. 1. A germanium blank, about one-tenth inch square and a few thousandths of an inch thick, is held on the transistor stem, which itself is attached to a precisely machined

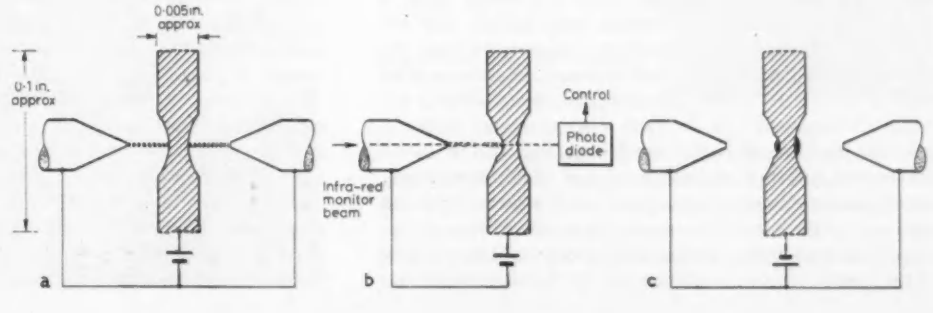


Fig. 1 Etching a germanium blank and plating indium electrodes on it

a. Rapid rough etching is carried out electrochemically by jets of sulphuric acid solution

b. Infra-red gauging allows the depth of etch of the germanium blank to be accurately controlled during the stage of precision etching

c. Jets of indium sulphate directed onto each side of the germanium blank produce plated indium electrodes

work carrier. Accurate positioning is thus assured for mechanization of the subsequent electrochemical etching operation used to produce concentric pits on opposite sides of the germanium blank. The first, or 'rough etch', stage is carried out by allowing jets of a sulphuric acid solution to impinge on each side of the blank. Jet pressures and temperatures are carefully monitored and the etching done on a timed cycle.

After rough etching the work carrier automatically transfers to the 'precision etch' head, again being precisely located in relation to the etch jet impinging on what will ultimately be the emitter side of the germanium blank. It is at this critical stage that the 'base width', and hence the frequency range of the transistor, are determined. Projected through the etch jet, while etching is proceeding, an intense beam of light is focused on the emitter etch pit. The infra-red component of this beam traverses the germanium and the transmitted intensity is monitored by a small photodiode mounted in line. It is possible to correlate the intensity, and hence the photodiode signal, with the thickness of germanium remaining between the emitter and collector etch pits. When the signal reaches a predetermined value a solenoid valve is triggered and the flow of etchant automatically cut off. Effectively, the web of germanium remaining between the etched regions becomes the base thickness of the transistor and by this means can be automatically controlled to a few hundred-thousandths of an inch. Fig. 1b shows diagrammatically the precision etch head illustrated in Fig. 2. To ensure accuracy and consistency of etch profile several precautions are necessary. For example, small aspirator tubes on each side of the germanium draw off the used etchant so that none is recirculated at this critical operation. Also, a stream of air is blown onto the collector side of the blank to prevent any accumulation of etchant in the collector etch pit, as this would obviously interfere with thickness monitoring.

Fig. 2 This precision etching head controls the base thickness of the germanium transistor to within a few hundred-thousandths of an inch

Electrode plating and concentricity control

After the etching processes the work carrier is again automatically transferred to an electrode plating head. Here jets of indium sulphate solution are simultaneously directed on each side of the germanium. The germanium is held at a negative voltage in this head with the result that indium dots (some two or three thousandths of an inch in diameter) are plated into the emitter and collector etch pits. This plating process is again closely monitored for jet pressure, temperature, and plating time, and aspirators ensure that no recirculation of plating solution occurs. To obtain a clean substrate for plating, the jets are initially turned on with voltages in the *etching* direction. After a fraction of a second the voltages are automatically switched to the plating direction. Diagrammatically the process is shown in Fig. 1c, and in Fig. 3 the plating head itself is illustrated.

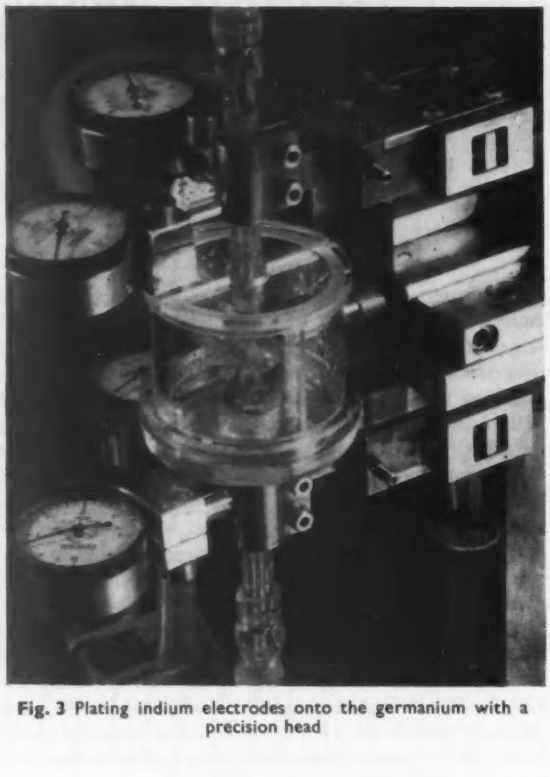


Fig. 3 Plating indium electrodes onto the germanium with a precision head

Satisfactory operation of the transistor requires proper control not only of electrode diameter but also of electrode concentricity. This is checked visually in a dual-beam microscope shown in Fig. 4. The transistor, still indexed in the work carrier, is placed with the germanium blank vertical and centrally situated between the microscope objectives. Each electrode can then be viewed in the respective eyepiece and any deviation from concentricity measured on a graduated eyepiece scale. Should either plated electrode be offset with respect to the other, or within the corresponding etch pit, a micrometer adjustment in the appropriate direction can be made to the plating or etching jets as required.

The processing carried out to this stage results in a device

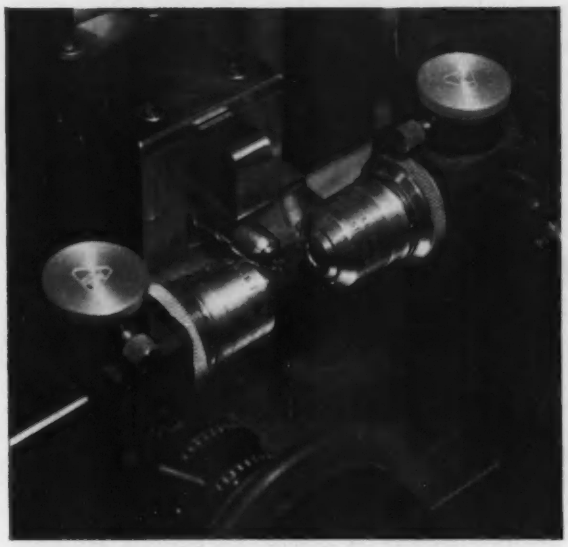


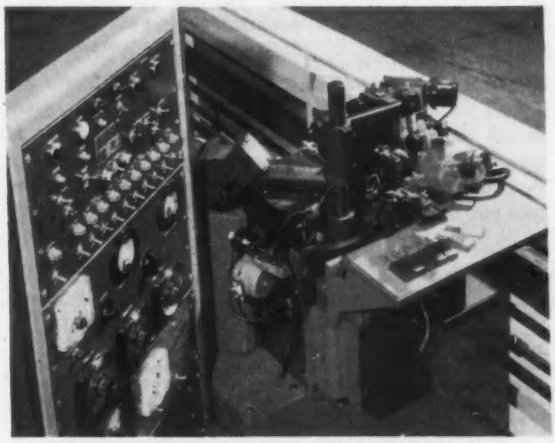
Fig. 4 By a dual-beam microscope a production inspector can determine accurately whether or not the emitter and collector electrodes are concentric

which, although the electrodes are not yet connected to operating leads, can nevertheless show transistor action. A further control is therefore inserted after the plating stage where a preliminary electrical test can be applied. The work carrier is again automatically transferred to a test head, where, by actuation of a microswitch, two very fine probes are delicately traversed into contact with the emitter and collector electrodes. Application of appropriate voltages to the probes then produces a reading on a moving-chart recorder indicating whether the transistor is within the electrical tolerances required for the particular type. 'Controlled manufacture' has basically determined the main electrical characteristics of the transistor at this stage, and the automatic transfer and processing mechanism described allows of transistors being passed continuously through a single line at a rate of many hundreds per day.

Automatic lead attachment

It is necessary next to attach fine wires, generally called 'whiskers', to the centre of the emitter and collector electrodes

Fig. 5 Attaching whisker wires automatically to the emitter and collector electrodes



and then weld these to the external leads. While these operations are sometimes done manually, most Semiconductors Ltd germanium and silicon transistors are processed on a recently developed automatic whisker attacher which combines the preparation and bonding of whiskers in one precise mechanized operation. A chemically cleaned and fired spool of wire is fed into the auto-attacher, the first machine operation being to electroplate a globule of indium-cadmium alloy (approximately two-thousandths of an inch diameter) on the end of the wire. After this plating operation jaws move in to grip the whisker, and bend it to shape. The transistor, still indexed in the work carrier, is then fed to the work head, and the plated whisker wire traversed into light contact with the electrode. A heater bar now moves near to the wire and applies a timed heat cycle, sufficient to melt and bond the whisker wire to the electrode. Clearly one must position the whisker wire in relation to the electrode very precisely, and to achieve this a split-chopper photoelectric system is used in conjunction with servos. This mechanical-optical control ensures that the whisker wire is brought slowly and exactly into the required position for every transistor. The operating head and control panel of the automatic whisker attacher is shown in Fig. 5. After bonding to the electrodes the other ends of the whiskers are welded on conventional hand fixtures to the main leads projecting up through the transistor stem.

Testing

Transistor manufacturers aim today to provide a unit whose reliability far surpasses that of radio valves, and to this end stringent and comprehensive electrical and mechanical tests are applied. For the most part these tests are carried out manually, but to speed production some sequential switching test equipment may be employed. This is particularly useful

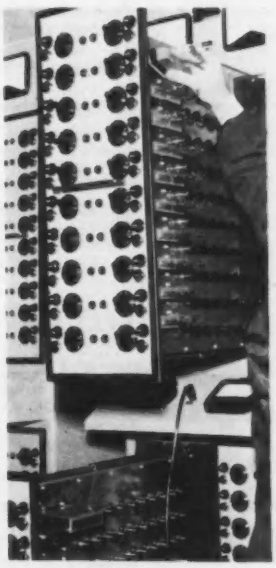


Fig. 6 Five thousand transistors can be simultaneously life tested in this rack

where special customer requirements, for example in computer applications, necessitate a number of characteristics being measured under a variety of operating conditions. Preset voltages can in these instances be rapidly switched in sequence to the transistor, and digital meters indicate the individual parameters.

Semiconductors Ltd transistors are, in addition, given a variety of life tests on a sampling basis. Racks, shown in Fig. 6, can handle 5000 units at a time, with the operating conditions of each transistor individually adjustable. The life test cabinets each have automatic temperature controls which, for germanium transistors, can provide steady-state ambient conditions up to 85° C, or cycled conditions. Each production batch sample is required to meet a high life-expectancy figure, both on storage at 85° C and on operation at 55° C. Correlations over many million transistor-hours are available which then allow guaranteed life under normal ambient conditions to be specified. At the present time, for most types of high-quality transistors, this is in the order of 100 000 hours.

Control of general ambient conditions

While mechanization and automatic controls ensure consistency and reliability during transistor manufacture, the full benefits of such control can be achieved only if the greatest care is taken to avoid extraneous contamination at all stages of production. Dust, water vapour, chemical residues and the like, are probably the worst enemies to reliability. To eliminate trouble from such sources, the Semiconductors Ltd factory at Swindon has been, literally, designed to enclose a controlled ambient atmosphere. Extensive dust filters and precipitators occupy an appreciable fraction of the volume of the building, while refrigeration and heating plant controls the temperature and humidity to close limits. Deionized water is used for all processing operations and is maintained at a minimum resistivity of 7 megohm-cm at the working points.

These precautions and facilities, combined with a degree of automatic control new to transistor production in this country, allows us to expect much higher efficiency and reliability than has previously been possible in the semiconductor field.

Summary

Some description has been given of certain aspects of transistor production in which newly designed and largely automatic machinery, based on electromechanical and electro-optical control systems, allows a near approach to mass production of germanium and silicon transistors. Closer device tolerances and the higher efficiency of production resulting from this new automation will rapidly bring to electronic designers the technical and economic advantages which ought to be available from the use of semiconductor devices.

LOOKING AHEAD

A diary for the next three months

NOV 16–23 *International Conference on Scientific Information.* See September p 128.

NOV 24–27 *The Mechanization of Thought Processes.* See September p 128.

NOV 28–DEC 4 *Electronic Computer Symposium and Exhibition.* See September p 128.

JAN 12–14 '59 *The 5th National Symposium of Reliability and Quality Control in Electronics.* Philadelphia. The Symposium is sponsored jointly by the Institute of Radio Engineers, the American Society for Quality Control, the American Institute of Electrical Engineers, and the Electronic Industries Association.

MEETINGS OF SOCIETIES

Institution of Electrical Engineers. Details from The Secretary, The Institution of Electrical Engineers, Savoy Place, WC2.

OCT 14 *The Scope of the Measurement and Control Section.* J. K. Webb.

OCT 28 Discussion on *Electronic Control of Machine Tools.*

NOV 4 *Operating Experience with the Transistor Digital Computer.* R. C. M. Barnes and J. H. Stephen.

NOV 6 *The Recognition of Moving Vehicles by Electronic Means.* T. S. Pick and A. Readman.

NOV 18 Discussion on *Ferro-Electrics.*

DEC 2 *Power-System Automatic Frequency Control Techniques.* F. Moran.

DEC 16 Discussion on *Modern Control Techniques on the Railways.*

JAN 6 '59 *Silicone Electrical Insulation.* H. Davis.

JAN 26 Lecture on *Automation.* H. A. Thomas. Tickets available during December on receipt of a stamped addressed envelope.

Royal Aeronautical Society. Details from the Secretary, Royal Aeronautical Society, 4 Hamilton Place, W1.

OCT 27 Lecture on *The Bloodhound.* D. J. Farrar.

DEC 18 Lecture on *Air Traffic Control Over the North Atlantic.* E. W. Pike.

Society of Instrument Technology. Details from The Secretary, The Society of Instrument Technology, 20 Queen Anne Street, W1.

OCT 20 *A Simple Data Read-Out System.* G. P. Tonkin and J. B. Bownas.

NOV 12 *Some Applications of Control Technique in Astronomy.* Dr P. Fellgett.

NOV 25 *Digital Data-Recording for Nuclear Experiments.* R. C. M. Barnes.

DEC 10 *An Experimental Approach to some Control Problems of Multi-Stand Rolling Mills.* H. Gill.

JAN 5 '59 *Control Systems as Applied to Railways Signalling.* J. C. Kubale.

JAN 14 *Symposium on Storage Media.*

LOOKING FURTHER AHEAD

FEB 16–17 '59 *Specialist Discussion Meetings* on new digital-computer techniques are being arranged by the Committee of the Measurement and Control Section of the Institution of Electrical Engineers. The meetings will be held at the Institution building. Details from the Secretary, Institution of Electrical Engineers, Savoy Place, WC2.

CORRECTIONS

We regret two errors in previous issues:

August: DATA SHEET—2, p 69. In line 8 of the right-hand column, '$\phi = 2$ arc sin $(2\omega_1/k_1)^2$ should have read '$\phi = \frac{1}{2}$ arc sin $(2\omega_1/k_1)^2$'.

September: CONTROL SURVEY—3, p 119. The Ketay integrating tachometer should have been shown as Number 105T2H and its voltage output as 1·0 ± 0·2 pc instead of 1·0 ± 2 pc.

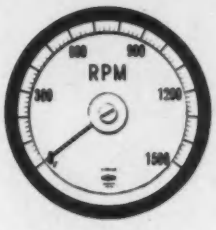


Fig. 1 *A rectifier-voltmeter type of indicator used with an a.c. generator tachometer*

ELECTRICAL TRANSDUCERS—2

Tachometers and Tachogenerators

by **A. J. MADDOCK, D.SC., F.INST.P., M.I.E.E.**

British Scientific Instrument Research Association

The first article in this series, by Dr J. Thomson, Director of BSIRA, appeared last month.

1. INTRODUCTION

A tachometer is an instrument for determining the speed of rotation of a machine shaft. An electrical output, in one form or another, is generated by the rotating shaft and this is used to operate the indicating instrument which may often be situated remotely from the actual rotating member: such an arrangement constitutes a complete tachometer. However there are other important uses for the generators, which will be considered in the later sections of the paper, concerned with their use in speed control and servo systems: for such service the generators must meet more rigorous specifications than is necessary for the normal speed indicators.

Only those systems which are in general use will be described. These are:

1. Magnetic-drag
2. D.C. generator
3. A.C. generator
4. Contact-making devices
5. Electronic.

Some instruments make use of a combination of two of these techniques in the complete system. Table 1 shows typical characteristics of these various types of tachometers.

2. MAGNETIC-DRAG TACHOMETER

This is the simplest speed indicator, widely used in motor-cars where direct drive to the tachometer can be arranged. The general accuracy is about $\pm$ 3 pc at the centre part of the scale. A permanent magnet, driven directly by flexible shafting, rotates in a soft iron cylinder: in the air-gap between these is located a cup, made of aluminium or copper, itself mounted on a shaft. Eddy currents induced in the cup react with the magnetic field and cause the cup to rotate: this motion is restrained by a spiral spring and the torque exerted balances that due to the rotating magnet. A pointer attached to the cup moves over a scale to indicate speed. Temperature changes cause the current in the cup to vary and these are compensated by varying the magnetic field in the gap. This can be done over a range of about 50° C by the use of shunts of a nickel-iron alloy whose permeability changes rapidly with temperature, thus increasing the field as the temperature rises.

A more robust type, for industrial and railway work, has the permanent magnet stationary and a soft iron rotor producing the revolving magnetic field. The accuracy of this class can be as good as $\pm$ 1–1·5 pc for speeds of 125–2000 r.p.m., full-scale, which can cover 300°.

3. D.C. GENERATOR TACHOMETER

This type of tachometer is bipolar with permanent-magnet pole pieces and wound rotor with commutator and brushes. The generated voltage is linearly related to speed, the latter often being limited to a top value of 1000–1500 r.p.m. The indicator, remotely situated, is a d.c. voltmeter with the usual swamp resistance to reduce temperature errors. This type is used industrially for rotational and linear speed indication and also in ships.

Modern alloys have a small temperature coefficient but it is usual to arrange a thermomagnetic shunt on one of the pole pieces to provide compensation for temperature variations.

4. A.C. GENERATOR TACHOMETER

4.1 Single phase, permanent magnet

An a.c. generator avoids the use of commutator and brushes and has no slip rings. It comprises a laminated

TABLE 1 *Typical characteristics of indicator tachometers*

TYPE	MAGNETIC DRAG		A.C. GENERATOR			D.C. GENERATOR	ELECTRONIC
	Magnet rotor	*Iron rotor*	*Magnetic rotor*	*Inductor*	*3-phase*		
Direct speed range, r.p.m. ..	100–2000	100–2000	300–10 000	100–500	500–10 000	300–5000	100–10⁶
Accuracy, pc	3–10	1·5	1	1·5	1	1	0·02–1

stator carrying distributed or lumped windings and a permanent-magnet rotor. An adjustable magnetic shunt is provided for initial calibration and for temperature compensation.

Electrical problems are now transferred from generator to indicator for not only does the voltage vary with speed but so also does the frequency. The indicating instrument should therefore have a high resistance so that the effects of generator and indicator reactance are reduced. These instruments are widely used industrially and in aircraft.

The usual indicator is the rectifier voltmeter. A linear scale is obtained except quite near the zero where it is slightly compressed by the characteristics of the rectifier: the effect is small and a typical scale is shown in Fig. 1. One method of compensating for temperature effects due to the rectifier is to insert a resistance with a large positive temperature coefficient (e.g. nickel) on the a.c. side of the rectifier.

A variant of the a.c. generator is that known as the inductor type. The spokes of a soft iron or steel rotor pass between pole pieces attached to a permanent magnet in the stator: the reluctance of the magnetic circuit is lowered considerably as each spoke passes through the gap and an alternating current is induced to flow in a winding on the stator and the indicator connected to it (Fig. 2). This is a robust system often used for railway work; either the rotor is driven direct by one of the running wheels or the wheel itself may be used as the rotor, having bosses formed on the side of each spoke. For a range of speeds between 20 and 80 m.p.h., the output frequency varies from about 30 to

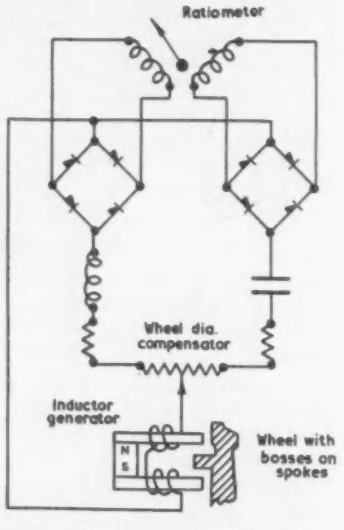


Fig. 2 This railway tachometer system uses an a.c. inductor generator

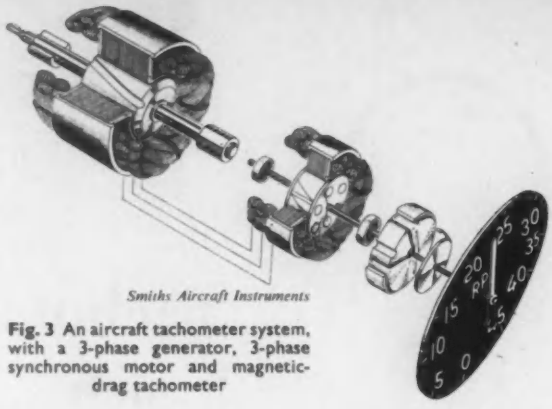
Everett, Edgcumbe, Ltd

120 c/s: the terminal voltage also increases with speed but to a much smaller extent. The indicator is a frequency meter of the moving-coil ratiometer type which gives an evenly divided scale with indications independent of voltage and resistance of the cables. A balancing resistor is included in the circuit to permit adjustment for variations in wheel diameter as wear takes place.

4.2 3-phase generator, motor and drag-cup

A form of tachometer particularly useful for the severe conditions encountered in aircraft is the 3-phase generator, with associated motor and magnetic drag-cup. The overall accuracy is about $\pm$ 1 pc; it is independent of the generated voltage but depends upon frequency varying with speed.

The 3-phase generator has a 2-pole permanent-magnet



Smiths Aircraft Instruments

Fig. 3 An aircraft tachometer system, with a 3-phase generator, 3-phase synchronous motor and magnetic-drag tachometer

rotor driven at speeds up to 3000 r.p.m., at which figure an output of nearly 30 VA is obtained. Current from the generator drives, at the indicator position, a synchronous motor, the rotor shaft of which carries the permanent magnet of a magnetic-drag-type tachometer, with its associated scale and pointer. Fig. 3 is a cut-away view of the complete system.

To achieve compensation for the wide temperature range likely to be encountered, a thermomagnetic shunt is used on the rotating magnet and the drag-cup is made of an alloy having intermediate conductivity and low temperature coefficient.

5. CONTACT-MAKING DEVICES

Several types of tachometer utilize a contact-making device driven by the main shaft: only the one using a capacitor charge and discharge system is fitted to any extent.

5.1 D.C. inversion

Basically this is similar to the 3-phase system of Section 4.2, but in place of the generator a mechanism closes a number of contacts in sequence, thus breaking up or 'chopping' a d.c. supply to simulate 3-phase current.

5.2 Electrical chronometric type

The shaft drives a single change-over contact, thus energizing two electromagnets alternately from a d.c. supply. An oscillating armature, having two pallet pins, allows an escapement wheel, driven by a synchronous motor through a slipping clutch, to revolve in step with the transmitted impulses. The rest of the equipment is of a normal chronometric integrating type with the clock motor measuring out intervals of one second, within which period the number of pulses will be proportional to the speed of the shaft.

5.3 Capacitor methods

A single-pole contact alternately switches a capacitor so that it is fully charged and then discharged. At constant voltage, the mean current flowing is a direct function of the number of contacts per second and hence of the speed of the shaft.

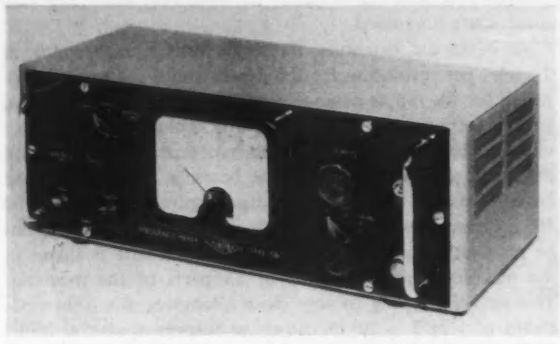
One method of working is to use a ratiometer as the indicator so that the system is less dependent upon the constancy of the voltage. Another method is to discharge the capacitor into a storage capacitor having a capacitance one hundred times as large: across this is a leak resistance so that a steady-state voltage is reached proportional to the speed.

These capacitor methods can give accurate results if due precautions are taken and can be used at low speeds. They have been used in speed control systems, particularly those of the Velodyne type.

6. ELECTRONIC TACHOMETER

Electronic circuits are well adapted to make precise determinations of time and pulse counts: hence they are suitable for speed determination on test beds or in the laboratory. There is the additional benefit that, if a photocell is used to pick up pulses of light from a patch painted on the shaft, no load is placed on the shaft and so this type may be used with very light mechanisms or for the determination of the highest speeds.

The basis of instruments of this nature is to determine the



Airmec

Fig. 4 An electronic frequency meter which can be used as a tachometer

number of pulses in a fixed time interval of 1 sec, which may be set up as a count on decade counter tubes to indicate the speed in r.p.s. Accuracies between $\pm$ 0·02 and $\pm$ 0·1 pc are obtainable depending on the speed over a range of, say, 1000 to 20 000 r.p.m.

These instruments require considerable electronic apparatus to derive the one-second interval from a valve-maintained 1000 c/s tuning fork through a series of divider stages. Simpler circuits, which will give accuracies of $\pm$ 1 pc and can be continuously operative, convert the input signal into a series of pulses of constant amplitude which are then rectified; thus their average value is directly proportional to the input frequency and hence to the speed. Such an instrument can deal with speeds of over one million r.p.m.: the lowest direct reading may be about 1000 r.p.m. but speeds down to a fraction of this may be determined by using multiple input pulses per revolution derived from alternate black and white strips on the spindle or from a slotted disc (Fig. 4).

7. TACHOGENERATORS

The characteristics required of tachogenerators when used in speed control systems or as the derivative-signal feedback generator in a servo system or a computer are more stringent than for the indicating instruments already described. As a consequence greater care in manufacture, and in use, is required. Two types of generator are in extensive use for this class of work, the permanent-magnet d.c. generator and the a.c. induction type with drag-cup rotor. The type used, d.c. or a.c., will depend upon the amplifying and control system and both have their own characteristics, advantages and disadvantages.

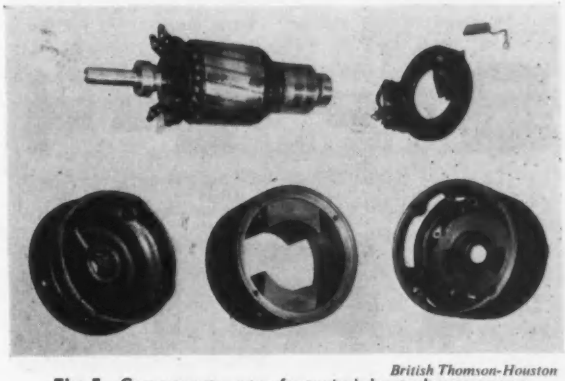
The principal features required are:

1. Linearity of voltage/speed characteristics
2. Freedom from superimposed spurious output signals
3. Constancy of output with time, temperature, and other environmental conditions
4. In a.c. machines, constancy of phase of output relative to input over the speed range.

7.1 D.C. tachogenerators

These machines can be wound to give substantial outputs, a typical figure being 20 V per 1000 r.p.m. with an output of a maximum of 0·1 A, the limit being set by commutation considerations. The brush drop must be reduced as much as possible to ensure accurate linearity of the voltage/speed characteristic: silver-graphite brushes and monel metal commutation bars assist in this and enable linearity to be obtained down to $\frac{1}{2}$ r.p.m. within a value of 0·02 pc.

The output of all d.c. generators contains a proportion of ripple. It is essential to reduce this, especially the low-frequency components, for it is at such frequencies that a speed regulating or servo system will most readily respond. The low-frequency component occurs at 1 and 2 cycles per revolution and is caused by uneven air-gaps, slight eccentricities in rotor and stator, and variations in permeability of the rotor magnetic path. The effects of these are reduced by using comparatively large air-gaps, by stacking the rotor laminations systematically on the shaft so that the 'grain' of the metal is oriented round at least one complete turn, and by maintaining high machining and assembly accuracy. As a result the low-frequency component does not exceed 0·5 pc at rated speed: however care must then be exercised in mounting and



British Thomson-Houston

Fig. 5 Component parts of a typical d.c. tachogenerator

driving the machine for otherwise this performance will suffer. Accurate alignment in the drive is essential and some form of flexible coupling is advantageous provided it does not allow torsional oscillations to be set up.

In addition there is the slot ripple at, say, 18 cycles per revolution which is kept as low as possible (less than 2 pc at rated speed) by skewing the armature slots, shaping the stator poles and offsetting these diagonally by half a rotor slot pitch. In any case, the speed used should not fall below that at which the noise components are comparable with the generated voltage.

Constancy of output to within 0·1 pc over a period of time and with variations of temperature and humidity can be achieved. The magnetic circuit can be stabilized against drift by short-circuiting the output, so that any subsequent accidental short-circuit will not necessitate remagnetization, and then by running in the factory for 24 hours. Rapid and spasmodic fluctuations in output are due to variations in brush contact drop through chatter and mechanical instability, and the brush gear must be designed to minimize these. Irregularities in the commutation film also produce slight variations in brush voltage-drop: these are a function of current, and so the impedance of the electronic equipment should be matched to that of the generator.

TABLE 2 *Typical characteristics of d.c. permanent magnet tachogenerators for control systems*

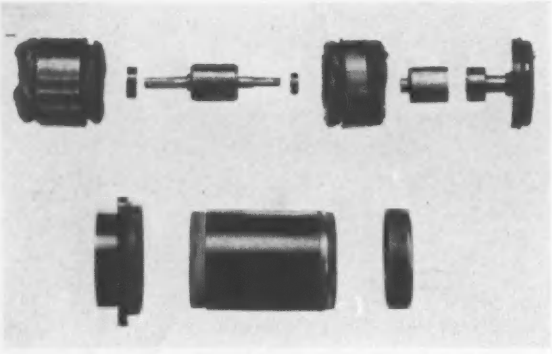
Generated output at 1000 r.p.m., volts	20
Linearity, pc	0·02–0·25
Ripple, pc	2
Speed range, r.p.m.	3000–8000
Temperature coefficient, pc/°C	0·003–0·015
Rotor moment of inertia, oz-in²	0·3–0·5

Although the modern magnet alloys have low temperature coefficients compensation is still required and thermomagnetic shunts are fitted to the poles so that the final temperature coefficient is not more than about 0·015 pc per deg C over the normal ambient range.

A dismantled generator of this type is shown in Fig. 5, and typical characteristics are listed in Table 2.

7.2 A.C. tachogenerators

This type of machine comprises a toothed stator with two separate distributed windings with their electrical axes at right angles resulting in a 2-pole machine, a cup rotor and a fixed, laminated core of cylindrical section inside the cup.



Evershed & Vignoles

Fig. 6 Component parts of a typical a.c. induction tachogenerator

A typical dismantled machine is shown in Fig. 6. One winding is constantly excited from an a.c. source and ideally no voltage should appear at the output winding when the rotor is stationary, owing to the quadrature arrangement of the windings. The core may be rotated slightly during initial setting up so that the best minimum is obtained: the core often has a flat on it to provide some degree of asymmetry to aid in this adjustment. As the cup is rotated the currents induced in it from the excitation winding couple with the output winding and an alternating voltage is developed which is directly proportional to speed and is of the frequency of the excitation current. Typical machines for 50 c/s operation generate 1 V or 8 V per 1000 r.p.m. and for 400 c/s 1 V per 1000 r.p.m.: their current output is low and they are normally used with a subsequent amplifier: for this reason they are not used in normal indicating tachometers.

As there are no commutator or brushes there is no ripple or fluctuation due to these but spurious voltages do occur in the output. At standstill this may amount to some tens of millivolts: this is due to the residual coupling between the two stator windings both magnetically and by direct inductive and capacitive linkage between the windings.

Stacking of the laminations of both stator and core so that the 'grain' of the material is disposed by at least one turn round the axis and careful machining of the stator, both in bore and equality of tooth sizes and spacing, and symmetrical spacing of the windings can reduce these figures by a factor of 10 or more, especially if a different winding and pole arrangement is adopted. This arrangement departs from the 2-pole configuration in favour of at least 6 poles, with the excitation and output windings staggered one slot pitch relative to each other: by this means cancellation occurs pole-by-pole and the difficulty of obtaining exact electrical quadrature is avoided.

As in the d.c. machines, there is a low-frequency ripple at 2 cycles per revolution for the 2-pole and 6 cycles per revolution for the 6-pole arrangement. This component is caused by any eccentricities in the rotor and is the combined effect of thickness variations in the cup, eccentricity of the cup on the shaft, and eccentricity in the bearings. This ripple may have a value of 3–10 mV, the larger figure occurring in the 400 c/s machines. Tests have shown that these figures can be reduced by a factor of at least 5 when care is taken in the machining and assembly of all parts of the machine. This entails working to very close tolerances, for total variations of 1 or 2 $\times$ 10^4 in. can cause outputs of several millivolts. Clearly, therefore, care is also needed in mounting the machines, particularly in aligning shafts and ensuring that no strain is placed on the unit. In any case the lowest speed should be kept above the level at which the noise voltages are comparable with the generated voltage.

Changes of output voltage with temperature are caused by variations in resistance of the cup rotor. This is often made of copper or aluminium and sometimes of an alloy of copper that has electrical characteristics which are a useful compromise between high conductivity and low temperature coefficient. A built-in thermistor and resistor network can be used for compensation by variation of the excitation current in accordance with machine temperature.

TABLE 3 *Typical characteristics of a.c. induction tachogenerators for control systems*

	NORMAL GRADE		SPECIAL GRADE
	50 c/s	*400 c/s*	*400 c/s*
Excitation, volts ..	50	50	115
Generated output at 1000 r.p.m., volts	1–8	0·5–1	1–3
Linearity, pc			0·15–0·3
Residual voltage, mV ..	15–20	20–100	5–15
Maximum speed, r.p.m.	10 000	10 000	10 000
Temperature coefficient, pc/°C	1	1	0·3
Rotor moment of inertia, oz-in²	0·03–0·05	0·03	0·03–0·05

Typical characteristics of the two grades of tachogenerator of this type are shown in Table 3. Some information about commercially available a.c. and d.c. tachogenerators was given in the *Control Survey* published last month. A particular advantage of the a.c. drag-cup tachogenerators is their low inertia. Typical figures are quoted in the table.

Many of the tachogenerators are now being made in the international frame sizes so that they are readily interchangeable.

Present trends in development are towards reduction of spurious output signals and improving linearity for systems which demand close tolerances, e.g. integrating systems for electronic computers.

PART 4

Simple frequency response analysis shows how a servo system behaves with any repetitive input signal

What is control engineering?

by **C. M. BURRELL**, M.A., B.Sc., A.M.I.E.E.
& **J. K. LUBBOCK**, M.A., B.Sc.
Lecturers in Department of Engineering, Cambridge University

IN THE PREVIOUS ARTICLE SOME EXAMPLES OF INPUTS BOTH practical and discontinuous were given. Discontinuous inputs are important because they yield relatively simple analytical solutions for the system response, and because these solutions completely characterize the system, i.e. the system response to a step input may be used, at least theoretically, to find the system response to an arbitrary signal. Another important input signal which yields a simple analytical solution for the system response is the sine wave. The sine wave response of the system over all frequencies also completely characterizes the system, and therefore its response to any arbitrary, but completely specified, input. However, the chief attribute of sine wave analysis is its suitability for theoretical and experimental work. The present article continues the discussion of discontinuity and sine wave responses.

Step response and stability

The step response of a position control system for various amounts of damping was shown in Fig. 9 of Part 3 (September, p 109). It is apparent from this diagram that:

a. An overdamped system responds most slowly, but does not overshoot.

b. An underdamped system reaches the desired value considerably more quickly than an overdamped system, but overshoots several times.

c. A critically damped system is intermediate between underdamping and overdamping; it has no overshoot but responds more quickly than an overdamped system.

The type of response which is best for a given application depends upon that application, but an intuitive assessment of these responses suggests that a slightly underdamped system is the best, as a compromise, between speed of response and overshoot.

This slightly underdamped condition would be selected as the best by using the area under a magnitude-of-error time curve as the criterion of performance. Thus a large area would correspond to poor performance and a small area to good performance.

With negative feedback the simple position control system which has been described can never be truly unstable; but if the damping could be made zero (this is not in fact physically possible) the output would oscillate continuously with an amplitude equal to twice that of the step input. This condition of continuous oscillation is called *limiting stability*, the system being on the verge of what we shall define as *true instability*.

In a more general system, the output following a step input may settle as time tends to infinity to:

1. A value equal or nearly equal to the input
2. A steady oscillation with finite limits
3. A steady oscillation with infinite limits
4. Infinite positive or negative value.

Conditions 3 and 4 are unstable; condition 2 is limitingly stable; condition 1 is stable.

Examination of the unit step response function for the system

$$\theta_o = \frac{s_2}{s_1 - s_2} e^{s_1 t} + \frac{s_1}{s_2 - s_1} e^{s_2 t} + 1 \quad \ldots (1)$$

shows that conditions 3 and 4 obtain when s_1 and s_2 have positive real parts. Condition 2 obtains when s_1 and s_2 are purely imaginary (i.e. have zero real parts). Condition 1 obtains when s_1 and s_2 have negative real parts.

Now s_1 and s_2 are the roots of

$$\frac{J}{K} p^2 + \frac{F}{K} p + 1 = 0 \quad \ldots (2)$$

This equation is called the characteristic equation of the simple system. For a general system we may write the characteristic equation in the form

$$a_n p^n + a_{n-1} p^{n-1} + \ldots + a_o = 0 \quad \ldots (3)$$

The equation has n roots, all of which must have negative real parts for condition 1, stability.

In passing, it should be noted that the roots will either be real or occur in conjugate complex pairs since all the coefficients of the characteristic equation are real quantities.

Sine wave response

Dependence and block diagrams for the position control system were given, respectively, in Figs. 8 and 6 of Part 3.

Upon application of a sinusoidal input a transient response occurs, with roots s_1, s_2; after a sufficient time has elapsed the transient decays into insignificance, the output being sinusoidal in the steady state, as will be seen from the following:

Consider the sinusoidal input

$$\theta_i = \theta_m \cos \omega t$$

where ω is $2\pi \times$ sine wave frequency

θ_m = sine wave amplitude

But

$$\cos \omega t = \frac{e^{j\omega t} + e^{-j\omega t}}{2} \quad \ldots (4)$$

as shown in Fig. 1. The steady-state system response to each of the two contra-rotating vectors is the same, except that for the clockwise vector a negative sign is associated with each $j\omega$ appearing in the expression which gives the response for the anticlockwise vector.

Furthermore

$$N \cos (\omega t + \phi) = N \frac{e^{j(\omega t + \phi)} + e^{-j(\omega t + \phi)}}{2} \quad \ldots (5)$$

so that if the device under test changes the magnitude of the real physical signal $\theta_m \cos \omega t$ by a factor N, and shifts its

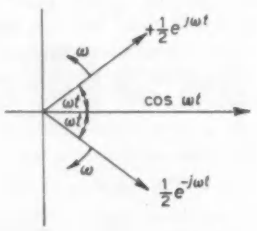


Fig. 1 Two rotating vectors make up the vector cos ωt

phase by ϕ, it will have exactly the same effect on the theoretically convenient, but physically unrealizable, signal $\theta_m e^{j\omega t}$.

In the steady state and with an input signal $\theta_m e^{j\omega t}$, the output signal of the position control system is given by

$$\frac{J}{K}\frac{d^2\theta_o}{dt^2} + \frac{F}{K}\frac{d\theta_o}{dt} + \theta_o = \theta_m e^{j\omega t} \quad \ldots (6)$$

The steady-state, or particular integral, solution of this

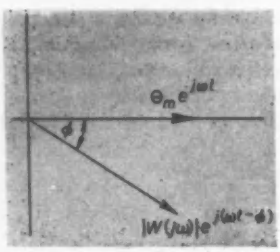


Fig. 2 Vector diagram for the output response $W(j\omega)$

linear differential equation is readily shown to be of the same form as the input, since

$$\frac{d^n}{dt^n} e^{j\omega t} = (j\omega)^n e^{j\omega t}$$

Therefore

$$\theta_o = \theta_m |W(j\omega)| e^{j(\omega t + \psi)} = \theta_m |W(j\omega)| \underline{/\psi(j\omega)}\, e^{j\omega t} = \theta_m W(j\omega) e^{j\omega t}$$

where $W(j\omega)$ is a vector quantity, relating θ_o and θ_m.

Substituting $\theta_o = \theta_m W(j\omega) e^{j\omega t}$ in (6) and rearranging, we get

$$\theta_o = \frac{\theta_m}{\sqrt{\left[(1 - \frac{J}{K}\omega^2)^2 + \frac{F^2}{K^2}\omega^2\right]}} \Bigg/ \overline{\arctan\left(\frac{\frac{F}{K}\omega}{1 - \frac{J}{K}\omega^2}\right)} e^{j\omega t} \quad \ldots (7)$$

and

$$W(j\omega) = \frac{\theta_o}{\theta_i} = \frac{1}{\sqrt{\left[(1 - \frac{J}{K}\omega^2)^2 + \frac{F^2}{K^2}\omega^2\right]}} \Bigg/ \overline{\arctan\left(\frac{\frac{F}{K}\omega}{1 - \frac{J}{K}\omega^2}\right)}$$

Thus the output response is sinusoidal like the input, but of different amplitude and phase. On a vector diagram (Fig. 2) we may represent the input vector along the real axis and the output vector lagging behind the input vector, since:

when $\omega = 0, \quad \phi = 0;$

as ω increases, ϕ decreases so that when

$$\omega = \sqrt{\frac{K}{J}}, \phi = \arctan -\infty = -90°;$$

and as $\omega \to \infty$, $\phi \to \arctan 0 = -180°$;

whilst $|W(j\omega)| = 1$ when $\omega = 0$

$$= \frac{K}{F\omega} \text{ when } \omega = \sqrt{\frac{K}{J}}$$

$$\to 0 \text{ as } \omega \to \infty$$

Since both $|W|$ and ϕ are functions of frequency, we can plot a locus diagram for the tip of the vector $W(j\omega)$ for different values of ω (Fig. 3). The vector $W(j\omega)$ is referred to as a 'vector multiplier' since when multiplied by the input vector it gives the output vector. The diagram shows the

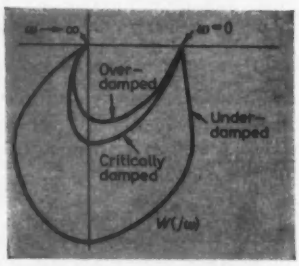


Fig. 3 The effect of damping on $W(j\omega)$

variation of $W(j\omega)$, i.e. the relation between sinusoidal input and sinusoidal output, in the steady state, for all values of ω between 0 and ∞.

Summarizing, we have shown that the response of the position control system to a sine wave input is obtained by multiplying the input signal by a vector multiplier $W(j\omega)$, which may be obtained by putting $j\omega$ in place of d/dt in the differential equation and treating $j\omega$ as an algebraic quantity. Thus for the general case in which the differential equation of the system can be written as

$$a_n \frac{d^n y}{dt^n} + a_{n-1}\frac{d^{n-1}y}{dt^{n-1}} + \ldots + a_o y = b_m \frac{d^m x}{dt^m} + b_{m-1}\frac{d^{m-1}x}{dt^{m-1}} + \ldots + b_o x \quad \ldots (9)$$

where $y(t)$ is the output function of time and $x(t)$ is the input function of time, we have

$$y(t) = W(j\omega)\theta_m e^{j\omega t}$$

where

$$x(t) = \theta_m e^{j\omega t}$$

and

$$W(j\omega) = \frac{b_m(j\omega)^m + b_{m-1}(j\omega)^{m-1} + \ldots + b_o}{a_n(j\omega)^n + a_{n-1}(j\omega)^{n-1} + \ldots + a_o} \quad \ldots (10)$$

The symbol p has already been used (Part 3, September) as an algebraic operator in place of d/dt. We may look upon p as an imaginary quantity $j\omega$ when the output is sinusoidal, but in general p is complex. Its significance will be dealt with in more detail in the next article.

Fourier analysis

The method of analysis developed in the previous section can be extended to non-sinusoidal but periodic inputs by the use of Fourier analysis. It is assumed in the following that the reader has a working knowledge of Fourier analysis (*1*). We may write

$$x(t) = \sum_{n=-\infty}^{+\infty} C_n e^{jn\omega t} \quad \ldots (11)$$

where

$$C_n = \frac{\omega}{2\pi} \int_{-\pi/\omega}^{\pi/\omega} x(t) e^{-jn\omega t} dt \quad \ldots (12)$$

Thus any non-sinusoidal periodic input can be Fourier analysed into a fundamental sine wave of period equal to the period of the non-sinusoidal input and a number of harmonic sine wave components of frequencies $n\omega$, where n is an integer and ω the angular frequency of the fundamental. The coefficients of the expansion are readily found by using equation 12.

In this way the system response to each input harmonic component can be found from the frequency response analysis of the system; then using the principle of superposition, the separate sine wave responses can be added to give the system response to the original non-sinusoidal input.

As an example of this technique, we will take an input

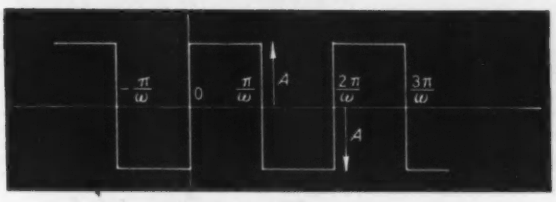


Fig. 4 Input square wave

which is a square wave (Fig. 4) of amplitude A and whose period is long compared with the settling time* of the control system

$$C_n = \frac{\omega}{2\pi} \int_{-\pi/\omega}^{\pi/\omega} x(t) e^{-jn\omega t} dt$$

$$= \frac{A\omega}{2\pi} \int_{0}^{\pi/\omega} e^{-jn\omega t} dt - \frac{A\omega}{2\pi} \int_{-\pi/\omega}^{0} e^{-jn\omega t} dt$$

* The time taken for the output response to settle to its steady-state value within a prescribed error, such that this error is never again exceeded.

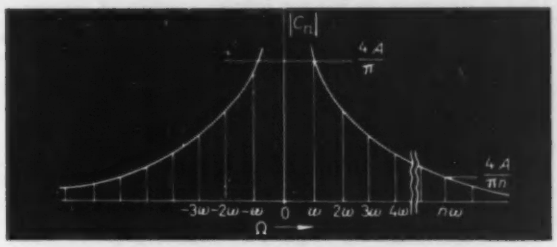


Fig. 5 A discrete spectrum for a periodic square wave

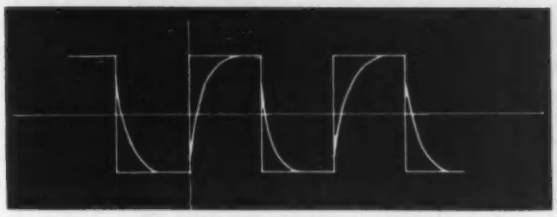


Fig. 6 Response of a critically damped system to the square wave of Fig. 4

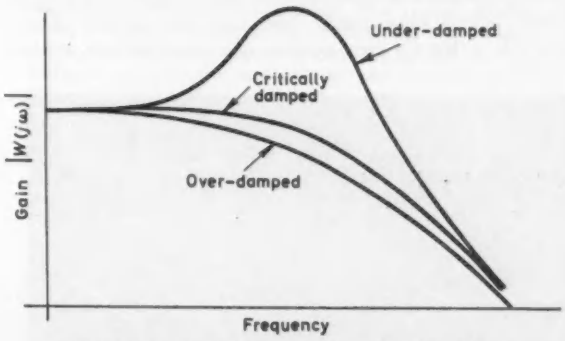


Fig. 7 System gain/frequency curves for three different degrees of damping

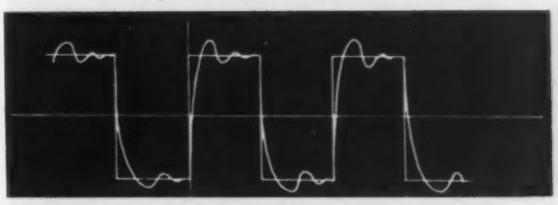


Fig. 8 Oscillatory response to the square wave of Fig. 4

$$= \frac{A}{2\pi nj}\left[e^{-jn\omega t}\right]_{\pi/\omega}^{0} + \frac{A}{2\pi nj}\left[e^{-jn\omega t}\right]_{-\pi/\omega}^{0}$$

$$= \frac{A}{2\pi nj}\left[2 - 2\cos(n\pi t)\right]$$

Therefore

$$C_n = 0 \quad (n = 0 \text{ or even})$$

$$C_n = \frac{2A}{\pi nj} \quad (n \text{ odd})$$

Hence

$$x(t) = \frac{2A}{\pi j} \sum_{n=-\infty}^{\infty} \frac{e^{jn\omega t}}{n} = \frac{4A}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \sin n\omega t \quad \ldots (13)$$

when n is odd.

Thus a square wave has an infinite number of frequency components up to infinite frequency. The spectrum, which is discrete, can be plotted as shown in Fig. 5.

Therefore, the position control system with a square wave input would give a response

$$\theta_o = \frac{2A}{\pi j} \sum_{n=-\infty}^{\infty} W(jn\omega) \frac{e^{jn\omega t}}{n} \quad (n \text{ odd}) \qquad \ldots (14)$$

Now since the period of the square wave is long compared with the settling time of the control system, from a knowledge of the step response we can expect the square wave response to look something like the curve of Fig. 6 (assuming say a critically damped system); and in fact we can see that this is the response given by equation 14, since for a critically damped system (Fig. 7) $|W(jn\omega)|$ will be smaller for higher values of n than for the lower values of n, and for the lower values of n, $|W(jn\omega)| \simeq 1$ because the period of the square wave $2\pi/\omega$ is long compared with the settling time of the control system. Thus only the higher frequencies will be attenuated by the control system causing a "rounding off" of the square wave as shown.

If the system was under-damped then $|W(j\omega)|$ (see Fig. 7) would have a value greater than unity over a band of frequencies ; thus for certain values of n the amplitude of harmonics would be greater than those in the perfect square wave, giving an oscillatory response (see Fig. 8). Very high frequencies would still be attenuated, however, giving still a finite rise time as compared with the zero rise time of the step.

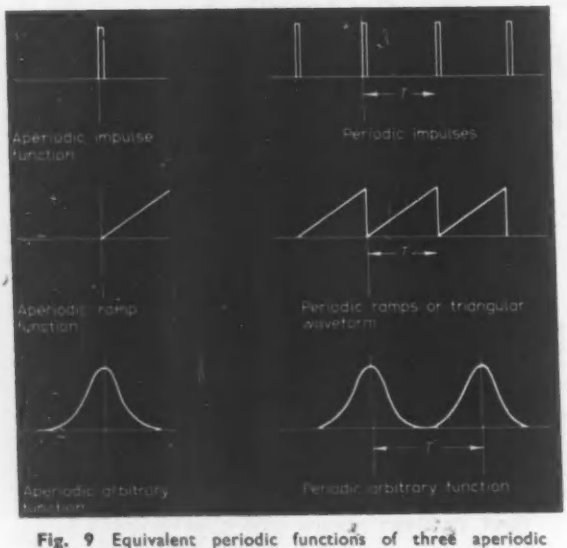


Fig. 9 Equivalent periodic functions of three aperiodic functions, where T ≫ settling time of control system

We have now succeeded in obtaining the step response of a system from its frequency response by considering the input to be a square wave (or repetitive step) whose period is long compared with the settling time of the system. This procedure of replacing an aperiodic input by a periodic one with a relatively long repetition period can be used for many aperiodic inputs. Some examples of aperiodic, and the corresponding periodic, functions are given in Fig. 9.

The procedure of making the period of the equivalent repetitive input long compared with the settling time of the system reaches its logical conclusion in the Fourier transform (*see Appendix I*).

Summary

The system response to any *arbitrary but repetitive* signal can be obtained by expressing the arbitrary signal as a sum of harmonically related sinusoids, each equivalent sinusoidal input being changed in magnitude and phase according to the value of $W(j\omega)$ at its particular frequency, to give a sinusoidal component of the output. The sum of all the sinusoidal components of output, gives the total output for the arbitrary repetitive input. This is done by means of Fourier analysis. The method may be extended to many non-repetitive inputs by the use of the Fourier transform.

Recalling Part 3 of this series, we see that we now have two methods of determining the response of a linear system to an arbitrary but completely specified input:

a. Using the system discontinuity

b. Using the system frequency response.

The second method has the unique advantage that for a sinusoidal input, the output must be sinusoidal. Thus the relation between input and output $W(j\omega)$ is a simple complex number for any given value of ω, and any linear system is completely characterized by the *response vector locus*, i.e. $W(j\omega)$ plotted for all values of ω from 0 to ∞ .

From the experimental point of view, measurement of $W(j\omega)$ involving only a numerical ratio and a change of phase can be readily carried out with sufficient accuracy, whereas the effect of the system on any non-sinusoidal signal is much more difficult to measure, since the input and output signals will differ radically in shape.

The roots of the characteristic equation of a linear system determine whether it is stable or unstable; roots having negative real parts being required for stability. System stability can also be determined from open-loop frequency response (a method of great importance) as will be shown in Part 5 of the series.

APPENDIX I

The Fourier integral

The method of replacing aperiodic inputs by periodic ones whose period is large compared with the settling time of the control system can be generalized by considering the limiting condition when the period of the equivalent input signal tends to infinity.

Then

$$x(t) = \frac{1}{2\pi} \sum_{n=-\infty}^{+\infty} X(j\Omega) e^{j\Omega t} \frac{\Omega}{n} \qquad \ldots (15)$$

where $\Omega = n\omega$

and

$$X(j\Omega) = \int_{-n\pi/\Omega}^{n\pi/\Omega} x(t) e^{-j\Omega t} dt \qquad \ldots (16)$$

and $x(t)$ is periodic of period $2\pi/\omega$.

Now as the period T tends to infinity, ω tends to zero and n tends to infinity.

We will write $\Omega/n = \delta\Omega$; then in the limit when $n \to \infty$ such that $\delta\Omega \to 0$, we have

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(j\Omega) e^{j\Omega t} d\Omega \qquad \ldots (17)$$

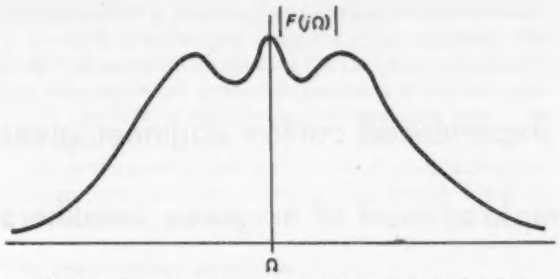


Fig. 10 A continuous spectrum of an aperiodic function

and

$$X(j\Omega) = \int_{-\infty}^{\infty} x(t)e^{-\Omega jt}\,dt \qquad \ldots (18)$$

by the definition of the definite integral.

$X(j\Omega)$ is known as the *Fourier transform* of $x(t)$,

and

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{j\Omega t}\,d\Omega \int_{-\infty}^{\infty} x(t)e^{-j\Omega t}dt \qquad \ldots (19)$$

is known as the *Fourier integral*.

Some functions $x(t)$ may not possess a Fourier transform owing to the lack of convergence of the integral in equation 18.

The following limitations on $x(t)$, known as Dirichlet's conditions, are sufficient to validate the above formal procedure:

1. $x(t)$ must be a single-valued function of a real variable t over the range $(-\infty, \infty)$ with a finite number of finite discontinuities.
2. At a discontinuity at t_0
$$x(t_0) = \tfrac{1}{2}[x(t_0+) + x(t_0-)]$$
3. The integral $\int_{-\infty}^{\infty} |x(t)|\,dt$ must exist.

Equation 16 yields a spectral function which is defined only at discrete values of $n\omega$ (since n is an integer and ω a constant). A typical plot of $|C_n|$ against $n\omega$, as shown in Fig. 5, consists of a number of distinct spectral lines spaced ω apart. As $\omega \to 0$, $\Omega = n\omega$ becomes a continuous variable and the spectrum becomes continuous (Fig. 10).

APPENDIX 2

The use of Fourier transforms in the solution of linear differential equations

By writing p in place of d/dt a linear differential equation with constant coefficients can be expressed as

$$A(p)y(t) = B(p)x(t)$$

where A and B are polynomials in p, $x(t)$ is the input function of time and $y(t)$ the output response.

Now a particular solution of the differential equation is

$$y(t) = \frac{B(p)}{A(p)}x(t) = W(p)x(t)$$

For a sinusoidal input:

$$x(t) = C\,e\,j\omega t$$

then $$y(t) = CW(j\omega)e^{j\omega t}$$

or $$\frac{y(t)}{x(t)} = W(j\omega),$$ where $W(j\omega)$ is in general complex.

Now let the input be a periodic signal of period T.

From equation 15 we may write

$$x(t) = \frac{1}{2\pi}\sum_{n=-\infty}^{+\infty} X(j\Omega)e^{j\Omega t}\delta\Omega$$

and

$$y(t) = \frac{1}{2\pi}\sum_{n=-\infty}^{+\infty} X(j\Omega)W(j\Omega)e^{j\Omega t}\delta\Omega \qquad \ldots (20)$$

Now for the more general case where $x(t)$ may be aperiodic, we let $\delta\Omega \to 0$ as $n \to \infty$. Then we get

$$y(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(j\Omega)W(j\Omega)e^{j\Omega t}d\Omega \qquad \ldots (21)$$

Hence the output of the system is given by the inverse transform of $X(j\Omega)W(j\Omega)$, where, from equation 20,

$$X(j\Omega) = \int_{-\infty}^{\infty} x(t)e^{-j\Omega t}dt$$

is the Fourier transform of the input signal, and $W(j\Omega)$ is the 'vector multiplier'.

Thus with the help of the Fourier transform we can obtain the system response to any input function whether periodic or aperiodic, using the above general procedure. The only limitation on the method is that the Fourier transform for the input function $x(t)$ shall exist.

Reference

1. Pipes, L. A : 'Applied Mathematics for Engineers and Physicists' (McGraw-Hill, 1958)

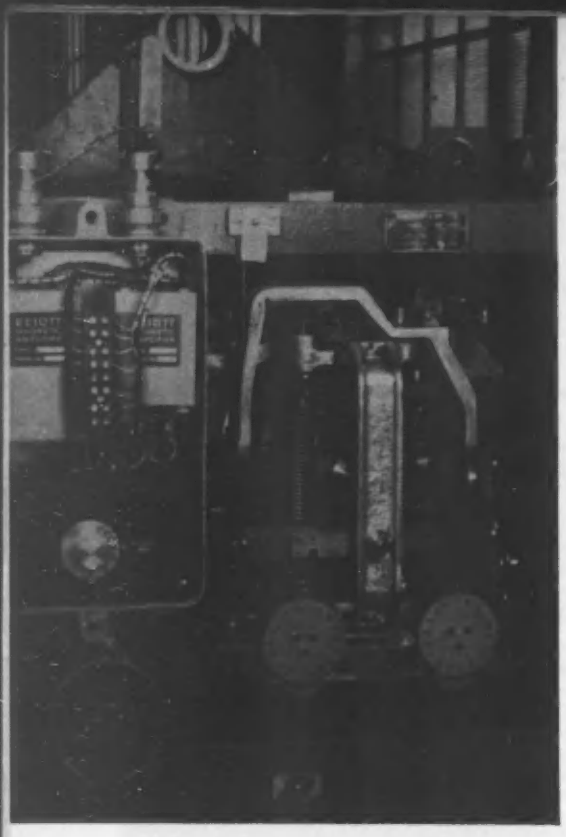
Ultrasonics ensures absolute cleanliness in control systems switch

THERMAL CONTROL LTD ARE NOW USING ULTRASONIC CLEANING IN manufacturing a range of precision switches for use in control systems. The switches depend on minute tolerances, and complete cleanliness in production is essential. One typical stainless-steel switch, designed to operate an electrical circuit in response to changes of pressure in fluids or gases, is suitable for corrosive materials such as nitric acid and high-test peroxide, and can be used for stage switching in rockets. Its normal working range is for pressures of 50–5000 lb/in², and it is tested to 10 000 lb/in².

The exterior of the switch (before it is sealed into a can) and its individual components are illustrated in the photographs. The main body consists of the two stainless steel disks on the left of the components, which have lapped mating faces. The thin diaphragm to their right is clamped between them and forms the pressure-sensing element. Slight movement of its centre causes the plunger in the centre of the lower disk to move the pivot arm, seen at the right centre of the components. This arm, mounted on a pair of precision miniature ball bearings, in turn actuates a Honeywell microswitch, fitted at the top of the device.

The switch is claimed to respond accurately to changes in pressure of less than 5 pc under the worst conditions. The slightest speck of dirt, or even of lapping compound, on any of the working faces would interfere with its action. Loose dirt, lodging in a corner, might not affect efficiency under test, but vibration in service might dislodge it later.

Achieving the meticulous standard of cleanliness required was virtually impossible by normal means, and ultrasonic cleaning is used. The equipment is made by Dawe Instruments, and the oscillation frequency is 40 kc/s. This output is fed to one of two electromagnetic transducers, each at the base of a cylindrical cleaning vessel, filled with benzene. The transducers convert the electrical signal into mechanical vibration. H.F. vibrations, resulting in rapidly alternating waves of pressure and rarefaction, give rise to the creation and almost immediate collapse of millions of tiny vapour bubbles. This process penetrates into the remotest interstices of any components immersed in the fluid. The components of the pressure switch are first cleaned individually, then as subassemblies. Each part is immersed for a period varying from a few seconds to two minutes. Finally, the whole switch is given a further immersion to eliminate any dust which may have been picked up during assembly. Immediately after the final pass the unit is sealed in a can.



An experienced control engineer gives a simple account of magnetic amplifiers and their application to control systems

FAST-RESPONSE MAGNETIC AMPLIFIERS

by **E. H. FROST-SMITH**, B.A., PH.D., A.M.I.E.E.

Director of Research, Staveley Research Department

APPLICATION OF MAGNETIC AMPLIFIERS TO SERVO CONTROL problems has been increasing in scope in recent years. This has come about with the increased tendency to think in terms of rugged reliability and of avoiding frequent servicing.

Servo engineers formerly viewed magnetic amplifiers with rather less favour than was, perhaps, their due. They were regarded as devices in which large power gains could be achieved in applications where a rapid response to input signal variations was not required. Although engineers knew that power gain could be sacrificed to achieve better response it was not until about 1950 that study of the various ways of making this sacrifice began. This led to the more frequent use of multi-stage cascaded amplifiers with a comparatively low gain per stage.

Servomechanisms involve the use of an output actuator which often possesses a comparatively long time-constant.

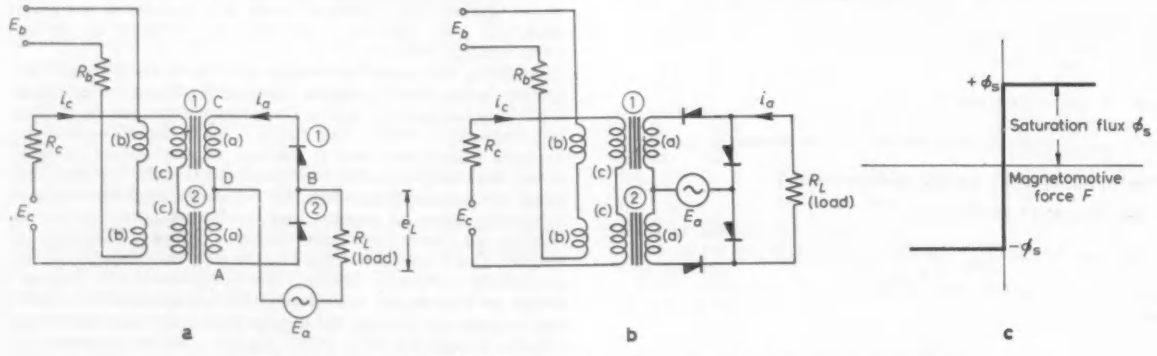


Fig. 1 Auto-excited transductor circuit

a Parallel connexion b Bridge connexion c Assumed magnetization curve for cores

The inclusion of an additional and comparable time-constant in the servo amplifier can cause the system to hunt. The amplifying device should therefore not introduce an additional long delay but should preferably comprise a number of much shorter time lags, as such a system will generally tend to be more stable.

This article gives a brief outline of the high-gain amplifier followed by a discussion of some of the circuits employed to produce faster response.

The transductor amplifier

The transductor is normally considered to be the basic amplifying device in a magnetic amplifier (*1*, *2*). It depends, for its amplifying properties, on the non-linear characteristics of iron cores and is generally used in conjunction with rectifiers.

The circuit for one well-known device of this type, the auto-excited parallel transductor, is shown in Fig. 1a. Another, the auto-excited bridge connexion, is shown in Fig. 1b. The latter circuit includes full-wave rectification giving a d.c. output. In both circuits the saturable magnetic cores 1 and 2 are each magnetized by a number of windings. One pair of these windings (a) is connected via rectifiers to a series load R_L and a low-impedance a.c. supply E_a. The other pair (c) forms the control circuit to which is applied the input voltage E_c

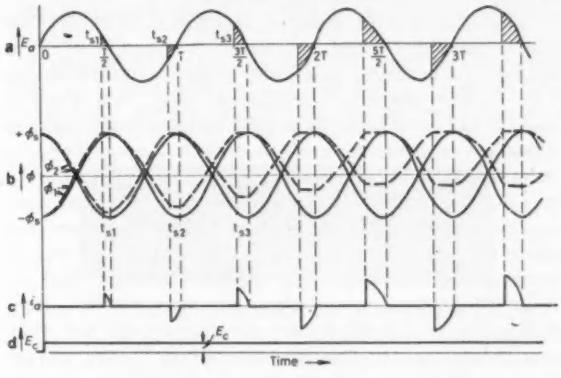


Fig. 2 Waveforms showing transients in auto-excited transductor after the application of a control voltage
a Voltage
b Flux
c Load current
d Control voltage

requiring amplification. A third pair of windings (b) is usually incorporated for biasing purposes.

On the assumption that each core possesses a flux/m.m.f. relationship approximating to that shown in Fig. 1c, it is seen that there are two states in which either core can exist—saturated or unsaturated. When either core is saturated the effective impedance in the a.c. circuit of the transductor is low so that nearly the whole supply voltage is sustained by the load R_L. When both cores are unsaturated the supply voltage is developed substantially across the transductor.

The cores saturate and desaturate cyclically at the frequency of the a.c. supply and the mean output voltage, $\bar{e}_L$, appearing across the load depends upon the relative time for which a core is saturated, which, in turn, is controlled by the magnitude of the input voltage E_c. Referring to Fig. 1a, if one considers the control voltage to be zero, the transductor can be so biased by an independent direct voltage E_b that the two cores never saturate throughout the cycle, with the a.c. supply alone. The bias is necessary to balance out a certain amount of d.c. control produced by rectification of the alternating current i_a. This, in effect, gives rise to a undirectional circulating current inductively maintained round the circuit ABC (Fig. 1a). When both cores 1 and 2 are unsaturated this unidirectional current is maintained round ABC causing both rectifiers to be conducting. Thus, under these conditions, on positive half-cycles of the supply the flux in core 1 will increase from $-\phi_s$ to $+\phi_s$ and the flux in core 2 will simultaneously decrease from $+\phi_s$ to $-\phi_s$; on negative half-cycles the two cores exchange their operation. Figs. 2a and 2b show the voltage and flux waveforms (solid lines in Fig. 2b) relevant to this condition. The effective inductance in series with the load is, at all times, large compared with the load resistance, and the mean load current is therefore small.

Suppose a unidirectional control voltage is suddenly applied at, say, time $t=0$ (Fig. 2d), and this is in a direction such as to cause a positive flux change in each core to be superimposed on the alternating fluxes. During the period from $t = 0$ to $t = T/2$ the flux ϕ_1 will increase more quickly and the flux ϕ_2 will decrease more slowly, as shown by the dotted curves in Fig. 2b. Thus at some time $t = t_{s1} < T/2$, core 1 will saturate, after which no further flux change will occur in this core until the next half-cycle. Over the period from t_{s1} to $T/2$ rectifier 1 is maintained conducting and a large current flows through the load and the path BCD (see Fig. 1a). Meanwhile the adjacent a.c. winding on core 2 is open-circuited owing to non-conduction of rectifier 2; this curve is therefore coupled to the control winding only, which gives rise to a considerably reduced rate of flux change. The variation in flux ϕ_2 therefore experiences a kink as shown at t_{s1}.

Core 1 desaturates at $T/2$, and in the following half-cycle the conditions are reversed. The flux ϕ_2 now proceeds towards saturation at the same rate as ϕ_1 did in the previous half-cycle. Since ϕ_2 starts from a higher initial value it reaches saturation sooner, i.e. at t_{s2}. During the interval from t_{s2} to T a larger mean load current flows, and ϕ_1 varies slowly during this period.

This state of affairs results in a cycle-by-cycle growth of current which approaches a steady state after a number of cycles which depends upon the circuit constants.

If G_v is the voltage gain of the transductor it can be shown (*1*) that this is related to the speed of response by the approximate equation:

$$n = G_v N_c/N_a \qquad \ldots (1)$$

where n is the number of half-cycles which elapse before the output reaches two-thirds of its steady-state value.

Also we have

$$n = 2f\tau \qquad \ldots (2)$$

where f is the supply frequency and τ is the time-constant.

It may also be shown that the time-constant τ can be expressed alternatively in the form:

$$\tau = L_{cw}/R_c \qquad \ldots (3)$$

where L_{cw} is the inductance of *one* control winding and R_c is the total control circuit resistance.

During a transient such as that described above, the control current increases with the load current until the steady-state is reached, for which the mean control current is given by

$$\bar{i}_c = \bar{E}_c/R_c \qquad \ldots (4)$$

To summarize the above discussion, the circuit variables which primarily concern us are the core fluxes, the

transductor voltages and the currents in the load and control circuits. During the steady-state operation the circuit variables are changing cyclically at the frequency of the supply and the values are precisely the same at corresponding times in successive cycles. The behaviour of the transductor over one cycle of the supply is governed by the initial conditions at the beginning of the cycle, and when a transductor is operating in the steady state, the initial conditions are the same at the beginning of every cycle. If a control voltage is suddenly applied to the input of a transductor which had previously settled down to a steady state of operation a new set of initial conditions is introduced. This causes a transient which may persist for several cycles before the transductor finally settles down to a different steady-state condition, the final conditions of flux, voltage, etc, at the end of any one cycle determining the initial conditions for the one following.

One leading point emerges from the foregoing discussion. The gradual build-up of the output current extending over several half-cycles arises because the initial conditions at the beginning of any half-cycle depend upon the mean output in the previous conducting period. This in turn is because flux changes in the unsaturated core are dependent upon the duration of saturation of the adjacent core.

By using only one core and arranging for this to be saturated at the end of every conducting half-cycle, the initial conditions at the beginning of every cycle would be the same, namely saturation. Thus, if a step voltage signal is applied at the

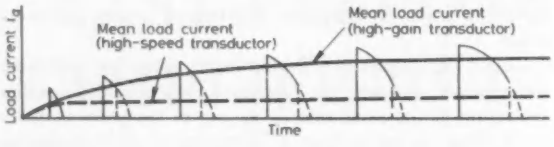


Fig. 3 The effect of limiting the integration time of a control voltage

beginning of one cycle, the next and subsequent cycles must be like that one since all start from the same initial conditions. Therefore the final mean output must be the same as the mean output of the first cycle.

The various types of high-speed transductor utilize this principle, which, in effect, limits the integration period for the control current, and hence the control component of the fluxes, to one half-cycle. It therefore follows that the steady-state mean output of a high-speed transductor is comparable with the mean output of a similar low-speed transductor in the conducting period following the first half-cycle for which control is applied. The difference is that the latter continues to build up in subsequent half-cycles while the former is reset to the same initial conditions at the end of every half-cycle.

The transient response shown in Fig. 3 makes this clear. The full-line curves indicate a slow response with a large output for a given input (i.e. a large gain), while the dotted curves which show full output reached in one half-cycle indicate a small steady-state output (for the same input) corresponding to a low gain.

In principle the circuits of Fig. 1 could exhibit both types of characteristic by suitable adjustment of the circuit parameters, e.g. the control circuit resistance. In practice however other factors cause flux damping besides the control circuit. The most troublesome of these is the closed circuit ABC, already mentioned, through the a.c. windings and the rectifiers. This causes transient delays which cannot be reduced by adjustment of the control circuit. Furthermore delays of this kind are non-linear owing to the presence of the rectifiers, with the result that the response time depends upon the sign of the signal. For signals which demand a decreasing output, the response is slower than for signals which increase the output.

These factors have therefore led to the development of two types of magnetic amplifier, namely those—already discussed—having a long time-constant but a high gain and those having a short time-constant and low gain.

For some servo applications a slow response may be used deliberately in order to stabilize systems where short delays are already present. This however leads to a sluggish servo. Usually the long lag is a cause of instability, and better performance in this respect is achieved by making the amplifier of several stages in cascade with a short time lag in each stage. Some circuits to achieve this will now be described.

Achieving fast response and required core characteristics

In general there are three practical ways of achieving a fast response with magnetic amplifiers. First by increasing the supply frequency; secondly by using the basic half-wave mode of operation with switching circuits to get full-wave action; and thirdly by voltage feedback.

Unquestionably the preferable method is to increase the supply frequency. There is however an upper limit to the frequency at which it is practicable to operate. At frequencies over 1–2 kc/s two main complications arise. First, the gain starts to fall off appreciably quickly owing to increasing iron losses and other inevitable parasitic effects. Secondly, and far more significant, is the difficulty of obtaining a high-frequency supply. This of course is readily achieved by means of valve oscillators, but if the equipment is to incorporate valves then often the case for using a magnetic amplifier collapses. Development of silicon power transistors may stimulate interest in high-frequency magnetic amplifiers, but here again such transistors would probably compete directly with magnetic amplifiers. We shall not here consider further the use

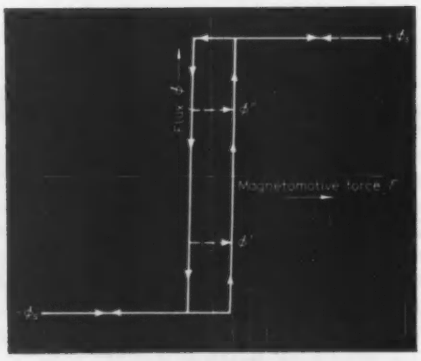


Fig. 4 Assumed shape of magnetization curve for high-speed transductor

of high supply frequencies as a means of obtaining fast response, and the two alternatives only will be discussed.

Both negative feedback and the half-wave mode of operation have the basic properties which limit the integration time of control to one half-cycle. For the latter type of circuit the

core material should possess a magnetization characteristic such as that shown in Fig. 4. The most important characteristic of such a core is that if the flux is at any level ϕ', then, on removal of the m.m.f., the flux will stay at that value due to remanence in the core.

Flux changes are most conveniently considered as being caused by the application of a voltage-time integral. Thus if a voltage E is applied to a coil with the flux initially at ϕ', then, so long as the core is unsaturated, the flux will change in time to a new value ϕ'', given by

$$\phi'' - \phi' = \int_{t'}^{t''} \frac{E}{N} dt \qquad \ldots (5)$$

where N is the number of turns on the coil and $t'' - t'$ is the time interval over which the voltage E is applied. On removal of the voltage at t'' the flux stays at the new value ϕ''. Equation 5 is only an approximation since it ignores the effects of coil resistance. However, provided the integration time is small so that the current has been unable to build up appreciably, it is generally a fair representation.

Transductor with half-wave rectified excitation

The half-wave transductor makes use of the above principle in the circuit of Fig. 5. This is basically the simplest practicable high-speed transductor and operates in the following manner.

If we suppose that the core is initially at positive saturation, then, on positive half-cycles of the supply voltage E_a, the rectifier will conduct and, since the core flux can increase no

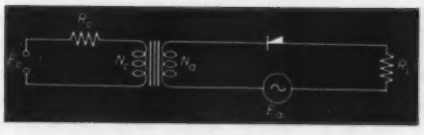


Fig. 5 Circuit of half-wave high-speed transductor

further, the a.c. coil N_a can support no voltage and the load current will be given by half-sine waves. On positive half-cycles we have

$$i_a = E_a/R_a \qquad \ldots (6)$$

On negative half-cycles the core remains at saturation owing to remanence and blocking of the rectifier. This is shown in Figs. 6b and 6c.

If a constant control voltage is applied at $t = 0$ (Fig. 6d) then, during the first negative half-cycle, this voltage causes a linear decrease of flux so that, according to equation 5, by the end of the negative half-cycle the flux will have decreased by an amount $(E_c/N_c)(T/2)$, as shown in Fig. 6e. Therefore on the next positive half-cycle the a.c. supply voltage has first to cause the flux to increase by this amount back to saturation before load current flows (Fig. 6f).

The mean load voltage depends upon the length of time for which load current flows, which depends on the saturation time in the positive half-cycle. Since this is governed by the amount of flux decrease caused by the control voltage in the previous negative half-cycle, it is evident that the mean load current is dependent on the control voltage. The dependence is shown by the two sets of diagrams in Figs. 6d, 6e and 6f for a small control voltage and Figs. 6g, 6h and 6i for a large control voltage.

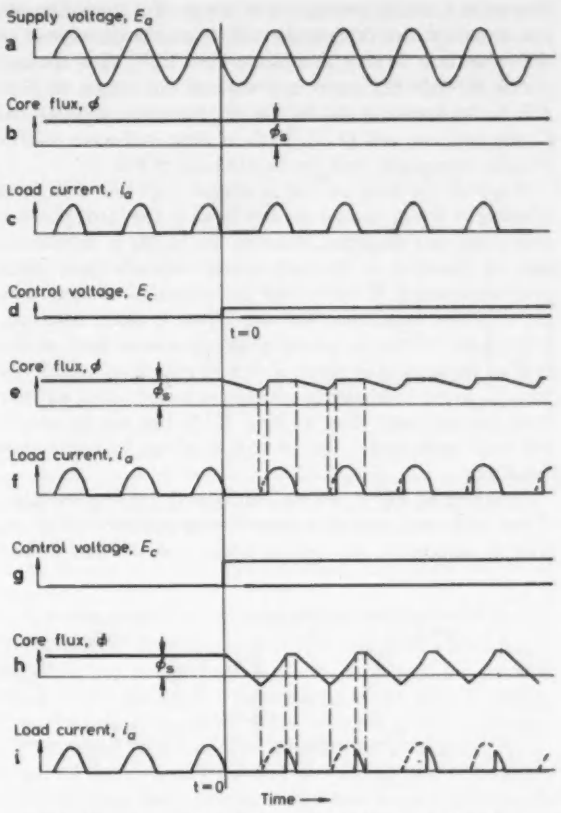


Fig. 6 Waveforms showing control of a half-wave transductor

It will be clear immediately that every positive half-cycle starts with the same initial conditions, namely those corresponding to saturation flux in the core. Therefore the full output in response to a step demand will appear in the first positive half-cycle after the one in which control has been applied for a full half-period. Thus it is seen that the response time can vary statistically between one and four half-cycles

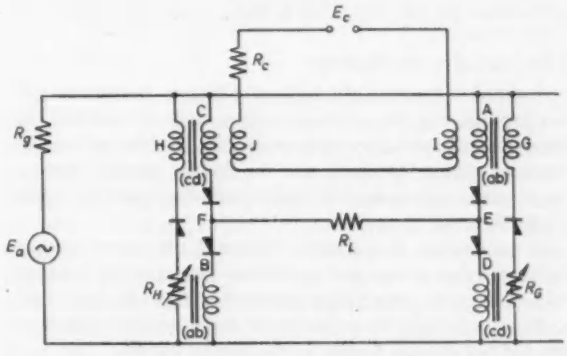


Fig. 7 Push-pull half-wave amplifier circuit (after Lufcy and others)

depending upon when control is applied. The power gain of a circuit such as this is usually limited to about 40.

Fig. 7 shows a push-pull circuit employing the basic half-wave circuit described above. It consists of four identical coils, A, B, C and D, linked by two cores. It should be noted

that coils A and B correspond to a pair of a.c. windings on one common core (ab), while coils C and D correspond to the other unit having a separate core (cd). Thus the a.c. circuit for one half-wave unit is from the supply through coil A, the load and coil B; the other circuit comprises coil C, the load and coil D (*3*). Each of these half-wave units is directly comparable with the basic circuit of Fig. 5.

If neither core (ab) nor (cd) is saturated, all four coils form a balanced bridge and no current flows in the load. If either one of the pair saturates, however, the bridge is unbalanced and the direction of the load current depends upon which core is saturated. If both cores are saturated all four coils are of a low impedance and the bridge is again balanced. The supply voltage is connected to the remote ends of the coils as shown and in series with a resistance R_g sufficiently large to avoid overheating during the period when all four cores are saturated. Bias windings G, H link the cores (ab) and (cd) respectively; the control windings I, J also link these cores.

Returning to Fig. 5, we see that one of the disadvantages of the half-wave circuits is that, during positive half-cycles prior to saturation, the control circuit and the load circuit are mutually coupled. This causes alternating currents to be induced in the control circuit which flow through the signal source and limit the power gain. The effect can be avoided by increasing the control circuit resistance but this also reduces the gain, since the full control voltage cannot then be applied to the control windings. This difficulty was first overcome by Ramey, who introduced a rectifier switching action into the control circuit as well as the load circuit.

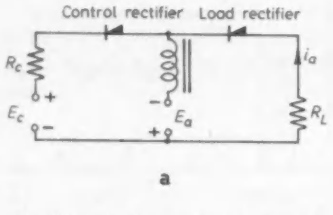


Fig. 8 (a) Half-wave Ramey transductor
E_a is shown for a positive half-cycle

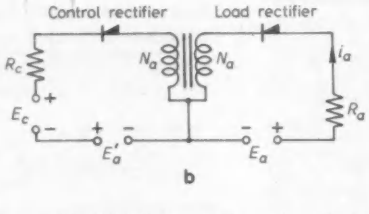


Fig. 8 (b) Half-wave Ramey transductor with separate load and control windings
E_a and E_a' are shown for a positive half-cycle

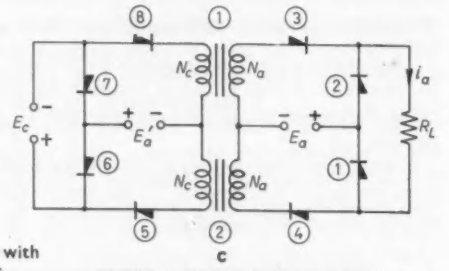


Fig. 8 (c) Full-wave Ramey transductor
E_a and E_a' are shown for a positive half-cycle

The circuits of Ramey

A simple version of the half-wave Ramey transductor (*4*) is shown in Fig. 8a; only one coil is used, to simplify the diagram and assist the explanation. On positive half-cycles the load rectifier conducts and the control rectifier blocks; on negative half-cycles the control rectifier conducts while the load rectifier is cut off.

In the absence of a control voltage E_c the supply voltage causes the flux to increase to positive saturation on positive half-cycles, with magnetizing current flowing in the load; and to decrease to negative saturation on negative half-cycles with magnetizing current flowing in the control circuit.

If a positive control voltage is applied this will be inoperative during positive half-cycles owing to the blocking action of the control rectifier. During negative half-cycles however the control voltage will oppose the supply voltage and cause the flux decrease to be less than it would have been for $E_c = 0$. Therefore the initial flux for the following positive half-cycle is above negative saturation and hence the supply voltage will subsequently cause positive saturation.

It is seen that control is similar to that effected in the half-wave case (previous section), but that now the control circuit is, at all times, isolated from the load circuit. Fig. 8b shows the more general half-wave circuit with two windings. This requires two a.c. supplies, E_a and E_a', adjusted so that

$$\frac{E_a'}{E_a} = \frac{N_c}{N_a} \qquad \ldots (7)$$

A full-wave version of this circuit is shown in Fig. 8c. This last arrangement (drawn for a positive half-cycle) shows that load current flows owing to saturation of core 2 while control is being applied to core 1. In this case rectifiers 1, 3, 5 and 7 are blocking. On negative half-cycles rectifiers 2, 4, 6 and 8 are blocking and the two cores exchange their operation.

This circuit has a response time within one cycle, and power gains between 100 and 200 can be obtained. The voltage amplification of these circuits is constant and equal to the turns ratio N_c/N_a.

Three-phase circuits

The single-phase circuits described in the last section can be extended for use with three-phase systems. The latter, in general, have a better performance and are particularly suitable for output power stages to control electrical machines. A paper by A. E. Maine (*5*) has been published on this subject and includes typical circuits. An application is discussed later in the article.

Fast response using voltage feedback

As might be expected, negative voltage feedback applied to an auto-excited transductor has the effect of increasing the speed of response of the amplifier while at the same time reducing and linearizing the voltage amplification. The full implication of this and its bearing on the fast-response circuits was first appreciated by Scorgie (*6*), who showed that the earlier circuits developed by Ramey represent a special case of a more general arrangement.

The circuit in Fig. 9 shows an auto-excited transductor using the bridge connexion in which a fraction of the output voltage is fed back to provide an additional source of control in series opposition to the actual control voltage E_c.

If this circuit is arranged to give zero output for zero input and, furthermore, if under these conditions the a.c. fluxes are varying from positive to negative saturation, the operation may be considered in three stages. First a control voltage is applied to the control circuit at a time $t = 0$. After a given time t, this produces a flux variation proportional to the magnitude of the total voltage-time integral applied to the windings from the instant $t = 0$. Secondly, this flux gives an output voltage whose mean value is pro-

portional to the mean flux level. Thirdly, a fraction of the output voltage is fed back to oppose the control voltage.

If the mean value of the voltage fed back is equal to the control voltage the former will oppose the control voltage as soon as the output appears. Therefore the total voltage-time applied to the control circuit will be the difference between that due to the control voltage and that due to the voltage fed back.

Now since the control voltage is applied at $t = 0$, the output voltage will not appear until one half-cycle later and thus in all half-cycles after the first the total voltage-time applied to the control circuit must be zero no matter how long a time interval is considered, since the mean voltage fed back is equal to the control voltage. Therefore the control voltage is only acting unopposed for the first half-cycle, during which time the applied voltage time is equal to $E_cT/2$. It follows that control can be effective during the first half-cycle only and the final output will therefore be established after this time. This, therefore, is an effective method of limiting the integration time to one half-cycle.

It will be noticed that the above discussion has ignored the voltage drop in the control circuit due to the inevitable build-up of mean control current. Provided the core permeability is large and the control circuit resistance is small, however, this voltage drop cannot build up sufficiently in the first half-cycle to produce an appreciable effect in opposition to the control voltage.

Thus this arrangement has characteristics which are very similar to those of the switched-rectifier type of circuit devised by Ramey, the most important being a linear voltage amplification equal to the turns ratio and a response time of one half-cycle. It has also two distinct advantages: first it is not so dependent upon a square-loop characteristic, and secondly it is more easily adjusted to the correct working condition.

Finally, it will be appreciated that the voltage fed back exercises the same type of constraint as the voltage drop in the control circuit of an auto-excited transductor due to the growth of control current. Both of these constraints reduce the voltage gain and speed up the response; as a method of achieving fast response, however, the latter is disadvantageous in that it is not the output which is fed back but, in effect, the control current. Therefore any time delays or non-linearities arising outside this local 'feedback' loop will not be influenced by it. Two such characteristics are immediately evident:

a. The time delay introduced by the a.c. windings (see the earlier section on 'The transductor amplifier').

b. Non-linearity between the control current and the flux, this being the most non-linear characteristic of the transductor.

When using the voltage-feedback type of circuit both of these effects are included within the feedback loop, and thus feedback is one of the most effective methods of producing a fast response.

Applications to control systems

Two typical applications of high-speed magnetic amplifiers to control systems are worthy of note. One of these is a fast magnetic amplifier servo for a motor speed control and the other a high-frequency vibrator amplifier.

Fast-response amplifier for motor speed control (5). In general, if the maximum speed of response is required from a motor speed control, the amplifier time lag must be reduced to a value which is small compared with that due to the motor inertia. When, however, the amplifier is operating from a 50 c/s power supply the response time is likely to be excessive if the whole gain is obtained from one stage. In such

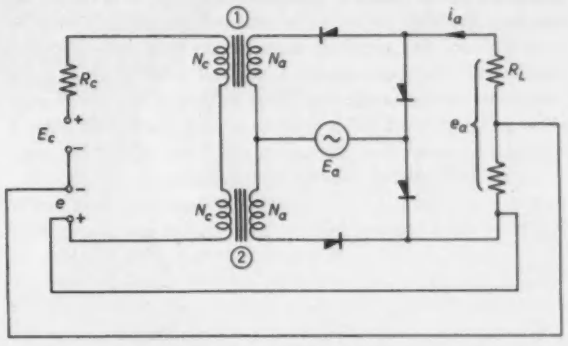


Fig. 9 Fast response obtained with an auto-excited transductor using negative feedback (after Scorgie)

cases, therefore, multi-stage high-speed amplifiers should be employed.

A two-stage three-phase magnetic amplifier has been designed along these lines for the armature control of a 3/4 h.p. d.c. motor having a speed range of 20 : 1. The motor speed is measured by means of a tachogenerator, the output voltage from this being compared with a constant voltage representing the speed reference. The resulting error signal is power amplified in a cathode follower which drives the first magnetic amplifier stage. Both magnetic amplifiers employ three-phase circuits of the type shown in Fig. 9.

The first stage employs six cores, each comprising $\frac{3}{8}$ in. stacks of HCR laminations (No 522). The turns ratio is 1·25 : 1 and each core unit is of normal transformer construction. The output stage, which is rated to supply a maximum output of 1 kW, consists of 6 HCR toroids, each one being of 6 in. diameter and having a sectional area of approximately 1.5 in². BTH germanium junction rectifiers are employed throughout.

When operating into a load of 200 ohms the overall power gain of the amplifiers is 16 000 and the response time approximately 1 period of the 50 c/s mains. The overall loop gain of the system is 38 dB.

500 W vibrator magnetic amplifier. Another application of the high-speed type of circuit is one in which an amplifier is required for energizing a moving-coil vibrator for aircraft resonance testing (7). The vibrator in question has been designed for operation from a 500 W electronic amplifier; but the advent of larger aircraft provided a need for lower frequencies (down to 1 c/s) than the electronic amplifier would handle. Further requirements were extreme robustness and compactness for field work; good waveform with a minimum of spurious outputs; and full power from less than 1 c/s to more than 100 c/s.

These considerations led to the design of a push-pull magnetic amplifier driven from a 3-phase 400 c/s motor-alternator. The moving coil of the vibrator is divided into two portions. These are connected to the two halves of the amplifier through a bridge circuit which removes the d.c. component of current from the vibrator, thus preventing overheating. The 'push' and 'pull' sides of the amplifier are quite separate electrically, except for a common supply transformer.

Each half comprises two stages and each stage is a full-wave three-phase circuit with the output voltage fed back in series with the input, as discussed previously, for single-phase amplifiers. The feedback enables the amplitude response of the amplifier to remain substantially constant for all frequencies up to 400 c/s, although a choke introduced for ripple smoothing causes some attenuation above 200 c/s. In order to use the amplifier conveniently with other existing equipment, the input signal is derived from a very simple electronic device employing three miniature double triodes. This drives the two half amplifiers in such a way that Class B operation is obtained. Signals of the order of tens of millivolts are sufficient to load the system fully.

For convenience in handling, the magnetic amplifier is mounted on a trolley. Leads to the trolley are for 3-phase 50 c/s mains, input signals, and output to the vibrator. In normal use, up to four of these units with four vibrators are used for multi-point excitation of airframes. Accordingly the four electronic pre-amplifier units are placed on a common panel in the control cabin. Means are provided for producing any desired phase relationship between the four signals, in order to suppress unwanted resonance modes.

Conclusions

There are two alternative ways of using magnetic amplifiers; in one case the power output for a given voltage input is limited by the circuit parameters (e.g. the control circuit resistance) while the response time takes a value consistent with the circuit amplification. In the other the time-constant is limited to one half-cycle while the power output depends upon the total control which can be effected in this time.

It should be noted that the voltage applied to the control circuit of the high-speed transductor is considerably greater than the control voltage for the low-speed transductor. This is because the control flux changes by the full demanded amount in one half-cycle only, and control must be supplied from a much larger e.m.f. source than if a larger number of cycles were available in which to control the flux.

The advantages and disadvantages of the two modes of operation can be discussed only with reference to a particular application. Where power gain may be sacrificed for improved response or a multi-stage amplifier is acceptable, the high-speed circuits such as this article describes are preferable. But clearly there are many applications of magnetic amplifiers to control systems with comparatively long time-constants—e.g. process control systems—where it is advantageous to sacrifice speed of response; this enables the control current to build up over a large number of cycles to a higher value for a given control voltage, thus giving a larger power gain with a longer time-constant than is obtained with high-speed circuits.

Acknowledgments

The author wishes to acknowledge with thanks the help and advice of his colleague Mr R. S. Taunton in the preparation of this article. Thanks are also due to the Directors of the Staveley Coal & Iron Co for permission to publish it.

References

1. Frost-Smith, E. H.: 'Theory and Design of Magnetic Amplifiers' (Chapman and Hall: to be published November 1958)
2. Milnes, A. G. and Law, T. S.: 'Auto-Self-Excited Transductors and Push-Pull Circuit Theory' *Proc. Inst. Elect. Engrs*, 1954, **101**, Part 2, p 643
3. Lufcy, C. W., Schmid, A. E. and Barnhart, P. W.: 'An Improved Magnetic Servo Amplifier' *Trans. Amer. Inst. Elect. Engrs*, 1952, **71**, Part 1, p 281
4. Ramey, R. A.: 'On the Mechanics of Magnetic Amplifier Operation' (part 2) *Trans. Amer. Inst. Elect. Engrs*, 1951, **70**, Part 2, p 1241
5. Maine, A. E.: 'Three-Phase High-Speed Magnetic Amplifiers' *Electronic Engng*, 1954, **26**, p 514
6. Scorgie, D. G.: 'Fast Response with Magnetic Amplifiers' *Amer. Inst. Elect. Engrs*, 1953, **72**, p 741
7. Taunton, R. S.: Unpublished notes on work done at de Havilland Propellers Ltd (see also Ref 1)

INDUSTRIAL PUBLICATIONS

A pictorial publication for the **transformer user** has been produced by the transformer section of Hayes Radio Ltd.
Tick **No 126** on reply card

The London Instrument Co Ltd present an illustrated booklet, with price list, describing their **electrical equipment.**
Tick **No 127** on reply card

Two pictorial leaflets have been issued describing automatic **winding machines** and **take-off stands** manufactured by Aumann of Loehne, Germany.
Tick **No 128** on reply card

An illustrated booklet covering a miscellany of **microswitch data** and current developments has been issued by Micro Switchcraft.
Tick **No 129** on reply card

Siemens Ediswan have produced a folder on **transistors** made up of sheets extracted from their Mazda loose-leaf valve manual.
Tick **No 130** on reply card

Siemens & Halske have produced a leaflet setting out their range of **small rectifiers** which have a higher rating and occupy less space than before.
Tick **No 131** on reply card

R. B. Pullin Ltd have a new four-page leaflet summarizing Pullin-Kearfott and Pullin **servo components** and instrument motors.
Tick **No 132** on reply card

A leaflet giving descriptions and dimensions of their **lever speed control** for 'F' type Carter hydraulic infinitely variable speed gears has been published by Carter Gears Ltd.
Tick **No 133** on reply card

Doran Instruments Ltd have published a list which covers a wide range of their **electrical measuring** instruments.
Tick **No 134** on reply card

A well printed publication describes Telcon plastic insulated multi-conductor **audio frequency cables** suitable for junction or trunk circuits between exchanges.
Tick **No 135** on reply card

A small well illustrated pamphlet has been issued by Elcontrol Ltd about their industrial **burner control** systems.
Tick **No 136** on reply card

'A Story of Temperature Measurement' has been published by Negretti & Zambra Ltd; in this booklet the evolution of the liquid-in-glass thermometer is described, from the early instruments of Galileo and Sanctorius to the present days.
Tick **No 137** on reply card

Electronic Switchgear Ltd have produced a small booklet compiled of various descriptive lists and technical data sheets of their **controllers** and other equipment.
Tick **No 138** on reply card

George Kent Ltd have issued a **list of overseas agents** who provide pre-sales and after-sales service. This alphabetical list details the technical facilities placed at the customer's disposal by Kent organizations throughout the world.
Tick **No 139** on reply card

Aerial ropeways using automatic control systems are proving increasingly useful in Switzerland

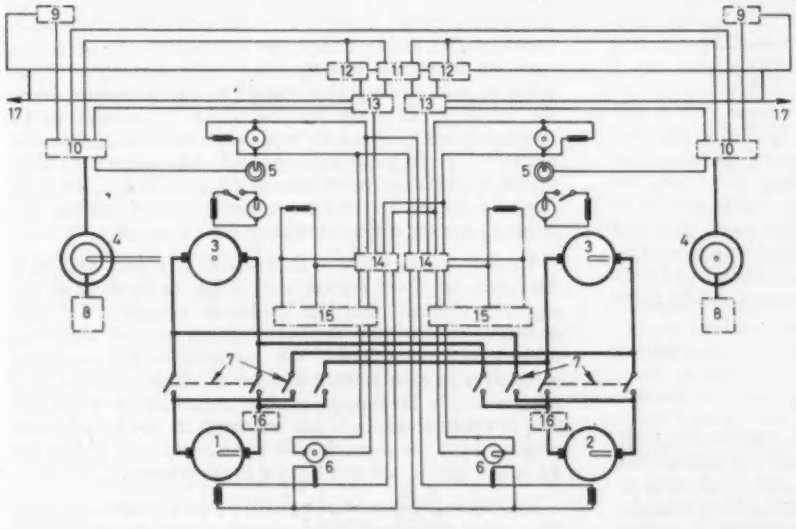
The Arosa Weisshorn Cableway

FOR PROVIDING CONTACT with communities in remote valleys and attracting tourist traffic in Switzerland the aerial ropeway giving a shuttle service has in many ways surpassed its competitor the funicular railway in recent years. Initial outlay and operating costs are lower and it is not so exposed to the hazards of avalanches and rockfalls. Thirty or so have been erected since 1955, the largest and most powerful stretching from Arosa to the summit of the Weisshorn—700 ft above sea level. Like the majority of the modern installations it incorporates automatic control and the equipment runs through the whole programme of starting, accelerating, retarding, stopping and shutting down the drives after the depression of a pushbutton switch.

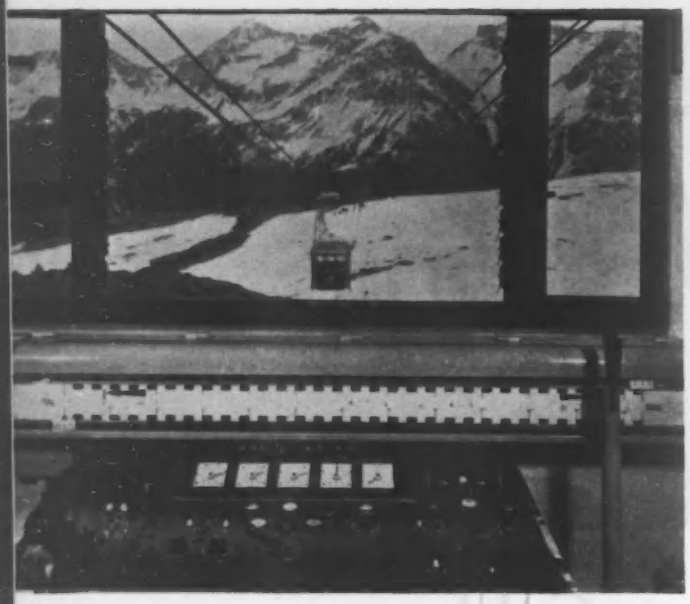
The ropeway is built in two sections, with both drives located in a middle station 261 metres above and 1252 metres away from the start. The second section is much longer (1982 metres) and rises 625 metres to the upper station 15 metres below the peak. The last span is 1340 metres, carrying the 3100 kg cabin with 76 passengers at a maximum speed of 7 m/s up the sheer face of the Weisshorn.

D.C. machines with converters used for drives

Power for the installation is drawn from the 10 kV ring main of the Elektrizitätswerk Arosa and stepped down to 500 V by transformers—one for each section—in the middle station. These are connected into the h.v. system by motor-operated convector circuit-breakers. An auxiliary transformer with the ratio 10 000/380 V supplies the house distribution system and can be used in an emergency to feed the drive



Schematic shows main electric drive and control equipment for the two sections: (1) Main drive motor for first section. (2) Main drive motor for second section. (3) Ward Leonard generators. (4) Main converter motors. (5) Exciter-converter sets. (6) Tachogenerators (d.c.) for speed control. (7) Change-over switchgear (d.c.) for switching the converter set over from one drive motor to the other. (8) Starting gear for the slip-ring motors. (9) Protective and metering equipment for each of the two drives, and controls for capacitor bank. (10) Switchgear and protective gear for main drive and the auxiliaries. (11) Central console in middle building, providing automatic push-button control of both sections. (12) Main control desk in control stand of each section. (13) Control unit for automatic programme control. (14) Control gear for excitation circuit with reference potentiometer and speed control. (15) Governor. (16) Protective gear for Ward Leonard circuits. (17) To controls and collectors for cabin equipment



Under the window overlooking the lower section the main indicator displays the positions of the cabins. The console carries the pushbutton controls, selector switches to choose the manner of operation (automatic, cabin control or manual) and instruments and signalling devices to show whether the ropeway is functioning correctly

controls. To improve the power factor, capacitors are connected on the l.v. side in parallel with the drives.

The main pulleys for each section are driven by separately excited 440 V d.c. machines operated from converters consisting of Ward-Leonard induction motors and generators. With a maximum of 730 h.p. the machine for the second section provides the most powerful drive yet installed on an aerial ropeway. In an emergency either section can be driven, though at reduced speed, by a petrol engine connected by belting to the high speed shaft of the main motor. Separate exciters are used for the main motors and generators in the form of compact three machine monobloc sets. In the circuit layout the main and exciter converters for either section are wired as a unit and could be switched over to the drive motor of the other if necessary. The three-phase slip ring motors of the main converters can be run up with only a light starting current, so that any harmful repercussions on the supply are avoided. The constant voltage of the flat-compounded self-excited main exciter is applied to the field of the drive motor and some of the control elements. The method of controlling the generator voltage by varying the field of an intermediate exciter is an even better method of providing stepless control of the running speed than the direct method, and the cabins can be stopped very accurately at a desired point. In addition they can be moved at a very low speed of only a few centimetres a second, which helps inspection and repair work considerably.

Pushbutton starts entire sequence

Each section has two different control systems and four control points, and the automatic programme control allows the installation to be controlled from any point and, if necessary, by technically unskilled operators. When a push-button switch is depressed, the entire programme is carried out automatically. All functions, such as running-up the converter, acceleration, retardation, stopping in the station and shutting down the converter are performed without the operator having to move a finger. The maximum speed, at present fixed at 7 m/s by the Federal Transport Bureau, will probably have to be raised in coming years, and with this in mind the programme control has been designed so as to enable the maximum admissible speed of 8 m/s over the supporting towers to be increased automatically to 10 m/s in the widest intervening span and afterwards reduced.

Programme is supervised by two indicators

The entire automatic programme is controlled and supervised by two indicators which are mechanically independent of one another. But regulations stipulate that even under automatic control the speed must be variable according to wind conditions, and additional pushbuttons allow it to be raised or reduced and the cabin to be stopped dead anywhere along the route.

The fine and stepless control of the generator excitation loses none of its significance with pushbutton control; the speed is regulated to the desired value over the entire speed and load range. Thus, in addition to affording other advantages, the automatic system can also be employed for the difficult inspection and maintenance trips.

The main control room for both sections is located in a central annexe of the middle station between the two motor-houses. A central console contains the various apparatus and instruments for operation and essential supervision tasks, and electric indicators showing the positions of the cabins. At this control point the transport capacity of the two sections can be adapted to the conditions by suitably adjusting the speed, thus avoiding long waits at the middle station. It also allows one machinist to control both sections. The advantages of this centralized control are particularly noticeable at times of heavy traffic.

Operators could take over

If the automatic system should break down the ropeway can still be operated by manual control from the stations or from the cabins themselves. Each cabin is equipped with a Gfeller light-current remote-control system and the signals are conducted to the drive controls by the insulated towing and trailing cables. Using this one man can operate the entire ropeway when there are only a few passengers, with the second cabin on the section travelling to and fro unoccupied. These cabin controls are especially useful in windy weather, where the operator can judge the best speed for himself, or for inspection and maintenance trips, when he can stop the cabin exactly in a particular spot. Another advantage is that the machinist can leave the middle station with the last run of the day, tripping the h.v. circuit-breaker by remote control from Arosa to put the entire installation out of service.

The last control point of each section is a main console in the upper and lower stations containing the instruments and signalling devices, and the apparatus necessary for both control systems. The various instruments and signalling devices indicate whether the installation is functioning correctly with each method of control, which is chosen by a selector switch. The change-over switches allowing the installation to operate with only one converter or one transformer, together with the controls and supervisory instruments for the petrol engine, are also housed in the console.

The ropeway has now completed a year of operation without a single stoppage of the automatic control equipment and

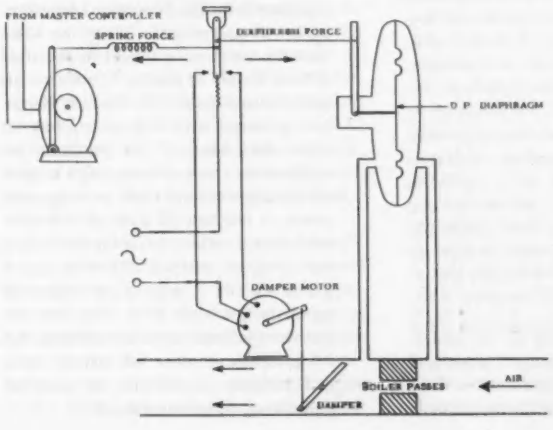
drives; these were developed by Brown Boveri & Co Ltd of Baden, who provided *Control in Action* with the accompanying photographs of the ropeway. Eleven of the nineteen sets of equipment supplied for ropeways by the company in the last three years have been automatic, and it is expected that with their lower running costs and greater convenience they will soon be universally used in preference to manually controlled systems.

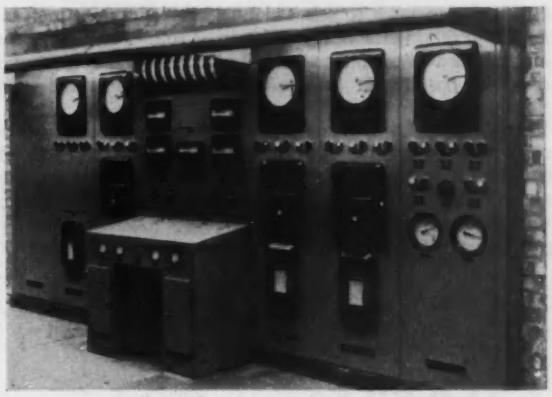
Automatic boiler control

Keeps pressure constant, saves time and money

WHEN THE LAST of four new boilers goes onto automatic control soon, hand operation will have been completely banished from the steam plant at British United Machinery's Leicester factory. Producing 120 million lb of steam a year for process work, heating the factory, and providing part of the power for running the machines by means of a back pressure turbine and generator set, the plant will be controlled in future by an all-electric installation which regulates combustion and keeps steam pressure constant. This was first put in last year and incorporated gradually into the plant to avoid any interruption of steam supply. Following tests carried out in conjunction with the manufacturers—Kelvin & Hughes (Industrial) Ltd—it was found that an increase of 7½ pc in boiler efficiency had been achieved over manual firing under

Airflow is controlled by a closed loop, with forces derived from the pressure differential across the boiler passes balanced against those from load



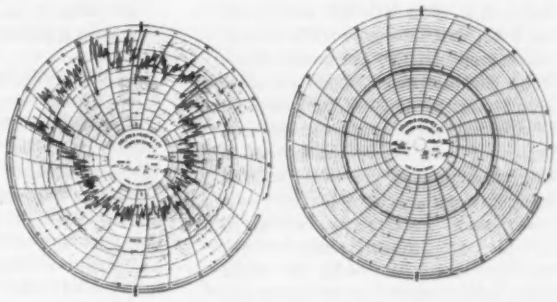


The master controller in the centre of the main panel signals to the individual controls governing airflow and coal feed

identical conditions, and the system was extended to control four Cochrane 'Economic' type boilers.

Each boiler is fitted with two Hodgkinson low ram, reciprocating bar stokers driven by a constant speed a.c. motor. Operating pressure is 140 p.s.i. for the heating and process work and superheat coils supply steam at 450° F for the turbines. Twenty feet away from the front of the boilers an illuminated panel carries the automatic control instrumentation, which is of the type shown by Kelvin & Hughes for the first time at the recent fuel efficiency exhibition (*News Roundup* last month).

A master steam pressure controller connected to the common steam header sends pulsed signals to individual combustion controllers which regulate the coal feed and air flow to each boiler. To regulate the coal feed, the signal pulses are relayed to a constant speed motor for cyclic operation which is predetermined in this case at 90 seconds, the



Even with the heavy fluctuations in load shown in the 24 hr steam flow chart on the left the controller holds the pressure variations to 3 p.s.i. from the mean of 137 p.s.i. (right hand chart)

running time being proportional to the load signalled by the master controller.

Airflow is controlled by a damper, operated by a push rod from a reversible a.c. motor through reduction gearing. A measurement is taken of the pressure differential across the boiler passes to produce an operating force on a diaphragm unit: output of this is in opposition to a control spring, tensioned by a square law cam which moves in response to the load signals. The resultant balance between the diaphragm and control spring positions a switch which controls a Nelson geared damper motor rated at 250 lb inch torque at 1 r.p.m. The airflow is thus controlled by a closed loop, which eliminates a critical damper characteristic.

Switches are provided on the combustion controllers to

enable the operator to select manual control and for increasing or decreasing the heat regulation at will. The controllers are balanced to permit load-sharing between the boilers, and once set require no further re-balancing unless the load sharing is to be varied.

At the end of a two-month period of continuous operation on automatic control recently 6·95 lb of steam per lb of coal had been produced. Turning up statistics for manual control last year it was found that the comparable figure was 6·3 lb of steam per lb of coal, so that for a yearly production of 120×10^6 lb of steam the consumption of fuel would work out at 7700 tons for automatic and 8500 tons on manual. At an assumed cost of 72/- a ton this means a saving of £2880 a year, apart from the benefits due to the maintenance of a constant pressure, which results in greater efficiency of the back pressure turbine and less waste in process equipment. The actual boiler efficiencies under the two regimes have been calculated as 78·5 pc and 70·9 pc. Running experience has thus justified British United Machinery's decision to use automatic control, and they say that their electrical maintenance problems are actually less than with mechanical systems.

Pick-off

by 'UNCONTROLLED'

MOST firms making instruments or automatic control equipment employ some control engineers, even though they may be called by some other name. But in only a few user firms will one find control engineers—as against instrument engineers, who normally busy themselves with maintenance, and perhaps development, of individual instruments rather than with whole systems. Recently I tracked two control engineers to earth in a large chemical works—the only two, I believe, among over 12 000 employees. Discussion with them about likely developments in process control was fascinating, yet a little like a cold bath on a hot day, after conversations with eager engineers in instrument firms. They felt that much, much more research must be done on the behaviour of chemical processes and the optimum design of plant before the pattern of instrumentation in chemical factories could change much—and they were doing such research themselves. In this they are probably right, but one of their opinions, which is heard fairly often today, is, to my mind, nonsense. This is that data-logging equipment and similar developments may be unacceptable on the grounds that one must give process operators a certain minimum amount of work to do. The argument savours of faddists who like 'crash' gearboxes in cars for the sake of exercising their skill in gear changing. Surely one can never gain by making jobs more complicated than they need be, other things being equal. The world will always contain plenty of difficult tasks; simplifying a job should release the man of more than adequate intelligence to tackle something more worth while.

I HAVE been reading Arthur Clarke's *The Exploration of Space*, recently issued as a Penguin in a revised edition. Control problems are not very fully discussed in the book, although in a chapter on travelling to the moon two methods of checking the spin of a spaceship are mentioned, and there is a short account of telemetering. Yet I recommend it as an objective but entertaining introduction to the problems of space travel. In the preface Clarke says that he is not going to make the common astronautical fault of being too conservative. He cites the enormous progress in planning for space travel since the first edition appeared in 1951. Nevertheless I cannot swallow his chapter on travel to the stars: one does not take a journey for the sake of unborn grandchildren.

THE American company of Texas Instruments, makers of silicon transistors, recently released news of their very successful trading for the first six months of this year. Glancing through their account of this, I was surprised to see the initials 'TI' cropping up as an abbreviation for the name of the company. Although this probably does not cause confusion in the USA, it might easily do so in this country, since Tube Investments, with widespread industrial activities, are commonly known by the same initials. However I gather the English subsidiary of Texas Instruments is not officially using the initials as an abbreviation (except in the form of a monogram), and I trust they will keep to this policy. Nowadays abbreviations are numerous and puzzling enough without being ambiguous as well. I hope the Editor will not complain if I say that CONTROL seems to show a slight weakness for abbreviations that a reader who is not 'one of the gang' may fail to recognize swiftly.

I was chatting recently to Dr James Kendall, who is the general manager (technical) of Texas Instruments. Referring to the cost of silicon transistors, he forecasted that by 1965 the prices of equivalent silicon transistors, germanium transistors, and valves would all be about the same. After that date the silicon transistor would be undercutting its rivals. Which would suggest that more English semiconductor firms will soon be thinking about silicon for transistors.

IN his Presidential Address to the British Computer Society, Dr Wilkes includes an intriguing account of the growth in accuracy of computations of π. It is a far cry from 1700, when π was known to 100 decimal places by use of series, to 1958, when π has been calculated to 10 000 places. I suppose most engineers carry four or five places in their heads (3·1416 or 3·14159), but it is easy to remember eight by use of the mnemonic 'See π here I state correctly to places eight'. (Readers must discover how to use it themselves.) Whether to do so has any practical advantage is doubtful. Dr Wilkes says that he has heard these computations described as the 'lunatic fringe' of scientific calculation. Nevertheless I am inclined to think that too many people leave school believing that π is exactly 22/7, and that all that is necessary for calculating it to any number of decimal places is some intensive division by 7. Certainly they do not realize, as Dr Wilkes says, that representing the ratio of the circumference to the diameter of a circle is not the most important property of π. The educational approach slightly echos the action of a senator in the fundamentalist American state who sponsored a bill to the effect that the value of π taught in the state schools should be exactly 3, because this value is used in the First Book of Kings. Not perhaps wise legislation, but no sillier than some of our purchase tax regulations. I remember buying a longish wooden ladder some eight years ago and sawing a few feet off it to get a shorter one, since a curious tax anomaly made it the cheapest method. To this day I gather that 11 ft ladders are subject to purchase tax while 12 ft ones are not. But there is hope: arbitrary mathematics by governments does not last for ever, and certainly π still has its accepted value in all American schools.

NEWS ROUND-UP

CHEMICALS

ERA will analyse shop takings

Boots the chemists are to go in for electronic data processing in a big way. They have just revealed that an ERA, the electronic scanner developed by the Solartron Electronic group, will be installed at their Nottingham office next February to read the till rolls from cash registers in their shops. Able to identify 250 characters per second, this will be the first ERA to go into commercial use and its application to the analysis of till rolls will be the first of its kind in the world. Following this move an EMIDEC computer will be put in to streamline the ordering of goods by the 1300 branches and maintain a perpetual inventory of the 60 000 lines in their warehouses. This will go in next summer and a pilot scheme in preparation for the system has already been started. The whole plan is part of a 'fundamental rethinking' of retail business methods, says general office manager D. S. Greensmith, who is also chairman of the Electronic Data Processing Committee of the Office Management Association. He hopes that eventually the computer will be able to carry out production scheduling of items made in Boots' own factories.

'Even blurred figures can be read'

About six thousand specially modified cash registers will be needed after ERA—Electronic Reading Automaton—goes into operation. It scans each figure on the till roll in a series of vertical strokes by a beam of light from a cathode-ray tube. The varying reflected light that comes from the paper is faithfully reproduced by a photocell as a varying electric current. Special circuits in ERA progressively 'clean up' the electrical waveform from the paper until it corresponds more nearly to the 'ideal' figure. The electrical picture of the figure is then impressed, element by element, on an electric 'store'. Logic circuits sort out its essential characteristics, identify it, and pass the result to the output lines. 'Thus ERA is well able to identify such smudged or blurred figures as would be found on, say, a second carbon copy, and is also able to compensate for misalignment', claims Christopher Bailey, Solartron's research director.

At Boots it will read the figures from till rolls supplied direct from the branches and feed them at the rate of 250 characters per second into a specially designed calculator which will analyse the figures in the various ways needed for control. A quick breakdown of these figures can add considerably to the effectiveness not only of the central administration but to the management of the individual shop. It will gradually replace a system of hand accounting by sales slips under which analysis of cash receipts may take some weeks to produce.

Extensive as the planned reorganization is, it still leaves room for improvements, thinks Mr Greensmith. 'The most unsatisfactory feature in the present plans', he states, 'is the necessity for hand punching of branch orders on to the tape that feeds the computer. Much time could obviously be saved if the orders received from the branches could be fed into the machine direct. Boots are at present financing research both by a commercial organization and by a university department in the hope of solving this type of problem.' Another desirable development would be the linking of the computer with the electronic scanning of till rolls from the shops. If the item sold were recorded in code on the cash register the actual sale could be made a means of reordering the product. This was technically possible but from a business point of view it was still far from practical. 'At the moment', Mr Greensmith says, 'it remains a target for the future.'

TITO VISITS UK INSTRUMENT DISPLAY At Zagreb President Tito, accompanied by his wife Madame Broz, is welcomed by Bernard Soloway of Kelvin & Hughes as he arrives to look over the company's mobile demonstration van which has been touring East European countries

CEC instruments to be made here

Following the agreement between the US Consolidated Electrodynamics Corporation and Elliott-Automation (*News Round-up* last month) preparations are going ahead for manufacture in this country of CEC's range of quality analysis instruments. These will include chromatographs, moisture meters, refractometers and oxygen analysers all designed for process use as well as a small mass spectrometer. The Corporation has held a lead in this field for some time in America and its instruments, together with those developed by Elliott-Automation, should make the self-optimizing plant a real and practicable possibility. They are designed for continuous operation under fairly hazardous conditions, and by bringing analysis out of the laboratory to 'on stream' use they enable continuous control to be carried out instead of routine sample checks which can only influence the average product quality.

OIL

New terminal uses auto pumping

London's new fuel oil terminal, opened at Poplar on 15th September, uses automatic pumping equipment to transfer oil from storage tanks to loading bays which enables nearly 400 000 gallons a day to be loaded on to road tankers. Occupying over four acres the terminal is supplied by barges unloading at a 700-ft quay and is equipped with storage tanks holding a total of about four million gallons. A fleet of road tankers

of up to 3600 gallons capacity is employed for distribution.

From the storage tanks the oil is automatically pumped to eight loading bays each fitted with three arms capable of delivering 300 gallons a minute. Automatic switchgear increases or decreases the number of pumps in action according to the number of road tankers loading. The amount of oil loaded is recorded by ticket printing meters on each arm and the accuracy of the meters is automatically checked by certified 150-gallon proving tanks and kept at a tolerance of 0·1 pc. Working at full capacity, 1200 gallons a minute of each grade of oil can be delivered. The whole installation cost nearly £5 million and has obviously been carefully planned by its owners, Charrington Gardner Locket (London) Ltd, for speedy turnover and minimum operating costs.

400 000 GALLONS A DAY Feeding oil from the storage tanks to the loading bays at the new Poplar fuel oil terminal, the automatic pumping equipment in the foreground entirely eliminates manual control

RAILWAYS

Computer aids GEC train design

The analogue computer developed by Professor E. Bradshaw of the Manchester College of Science and Technology for predicting the performance of new locomotives over given routes is finding increasing use in industry. The prototype was built by F. C. Robinson and Partners Ltd for British Railways and two further copies have been made, one for Metropolitan Vickers and the other for the General Electric Company.

The information supplied to the computer includes tractive effort and power demands of the engine and the resistance to motion at different speeds, and the gradient profile for the route travelled. It is inserted in the form of curves on punched tape and is continuously read as the speed and distance travelled varies. After being summed algebraically the information is fed to an integrator which evaluates velocity and is then integrated again to obtain distance.

The integrators used take the form of the familiar induction energy meter, as used for the metering of domestic electrical supplies. At each stage, velocity and distance outputs are employed to control the outputs of velocity-dependent and speed-dependent quantities which are used in the computation. Velocity is plotted to a base of distance or time, automatically.

The General Electric Co, who are now using one to help in the design of electric traction equipment, say that it produces accurate performance data in a fraction of the time required for conventional methods of calculation. In a recent test the predicted speeds of a train were checked against those read from a speedometer in an actual run and they found that errors compared very favourably with those of the speedometer itself!

The speeds at which an engine will travel over a given route are automatically plotted on the charts at the centre when graphs of engine statistics are mounted on the drum, and route information fed in on punched tape at the right

HOSPITALS

Moves towards auto sterilizing

Hospitals in this country, following the example of many in America and Europe, are beginning to realize that automatic control of the sterilization process for gloves, dressings etc may have many advantages over the old manual supervision. With some modern high temperature high vacuum autoclaves a complete cycle of evacuation, steam admission, second evacuation and hot air admission allowing pressure to rise again to atmospheric, can be achieved inside ten or twelve minutes. Working at this speed, it is no longer reasonable to rely on an operator changing over the valves at the correct moment by watching gauges, and the problem of automatic control becomes urgent. A firm which is doing a considerable amount of developing this is the Drayton Regulator and Instrument Co. Investigations started a year ago and a number of prototype controllers have now been produced. Once a push-button is depressed the sterilization process is carried out automatically and cannot be interrupted by misuse of the alternative manual control. The company is already developing the next step—an integrating mechanism which will automatically correlate temperature and time of cycle, thus simplifying the initial setting up process.

METALS

First controlled blooming mills

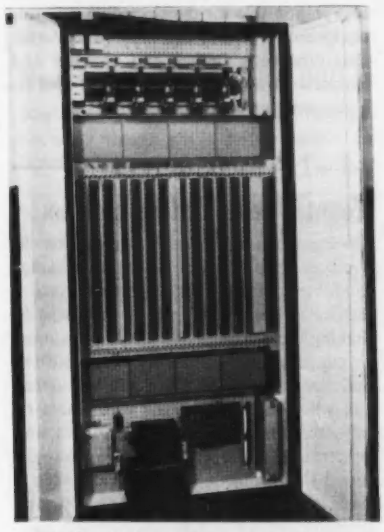
The working out of a BISRA idea called 'translator control' in the steel industry has helped in a big step forward in automation. Two reversing mills which incorporate automatic screwdown control —the first in the country—have now been completed. They are at Colville's and Stewart & Lloyds' works and both make use of the BISRA suggestion of employing GPO type uniselectors for information handling.

The new 48 in. steel blooming mill due to go into production soon at the Corby works of Stewart & Lloyds has been designed for a high degree of integrated automatic control. All the auxiliaries, including screwdowns, manipulators and roller tables, have been provided with Ward-Leonard instead of the conventional contactor drives, so that closed-loop position control can be applied when the need arises. With a plant as important as this, automatic control must be intro-

duced in stages, and prove itself as it goes, and in the first instance it will only be used on the screwdown mechanism. Later on, however, it is likely that extensions of the system of automatic control will embrace the manipulators, and possibly the main drive and roller tables.

100 full schedules can be stored

The screwdown control is naturally divided into two parts: the first concerns the precise positioning of the top roll according to small signals received from the second part, which is the information handling device. The position control is being provided by the Metropolitan-Vickers Electrical Co, who are the main electrical contractors, and the information handling device was manufactured under licence



The five high speed motor uniselectors with their associated control relays at the top of the cubicle automatically choose the appropriate screwdown setting for the mill in conjunction with the tag and plug programme boards mounted below

from BISRA by the Digital Engineering Co of London.

'The interesting thing about the information handling', BISRA's head of Laboratories, W. Jenkins, emphasized to CONTROL, 'is that it presents to the operator a completely rational set of controls. All the variables are in his own language and no special training in the selection of programmes or complicated procedure is involved. A hundred full schedules of up to seventeen passes each can be permanently stored in the machine and all he has to do is set four switches corresponding to the four essential variables—size of ingot, number of passes, and height and width of finished bloom size—and then to press the 'reset' or 'translate' button. As soon as the button is released the requirements set on the four switches are translated into an electric signal to position the top roll for the first pass. The only further action required from the operator during rolling is to press another button—labelled 'next pass'—once between each pass and the control produces the appropriate screwdown setting which it has selected. After rolling each bloom a further pressing of the 'next pass' button returns the top roll to the correct position for the first pass on a similar ingot'.

BISRA plans the next step

The main section of the translator control equipment is mounted in cubicles which are not normally accessible, and as such can be kept reasonably free from the effects of the mill atmosphere. There are two virtually identical main cubicles, one main and one standby, mounted back-to-back so that change-over can be effected in the event of a fault in a matter of a minute or two. At the top of each cubicle there are five high-speed motor uniselectors (standard GPO equipment) with the associated control relays. These switches control operations in conjunction with programme boards mounted below, which comprise tag and plug boards. Sub-miniature plug and socket connexions enable changes to be made easily in schedules if experience demands it.

Ingots can be 5 or 7½ tons and the finished dimensions vary between 8 in. and about 16 in. (cross-section about 100 in²). The number of passes must be added since entry and exit are on opposite sides of the rolls, and can be 9, 11, 13, 15 or 17, depending on the reduction required and the conditions of rolling. The temperature of the ingot particularly influences the number of passes and the decision usually involves the experience of the operator. It is obviously desirable to reduce the number of passes to a minimum, and the best operator can sometimes save passes by decreasing the number, after rolling has commenced, on the basis of the load taken in the first passes. 'It is a feature of translator control,' said Mr Jenkins, 'that such changes can be accommodated without interruption'.

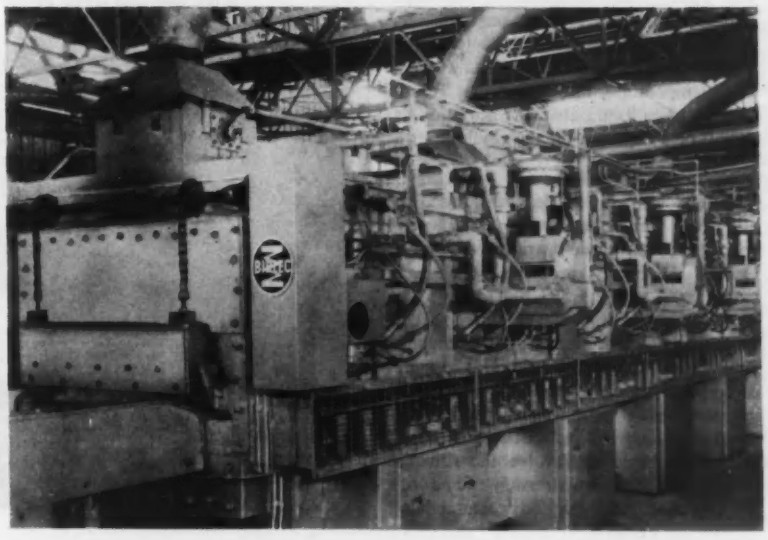
He foresees that the principle should find widespread applications in other industries. 'In the steel industry plans already exist for applying it to other types of mill, such as hot strip mills and high speed tandem cold reduction mills,' he went on. BISRA is working on the next step—automatic control for the manipulators—and still further ahead is the possibility of arranging for the 'next pass' button to be operated automatically after each pass; with feedback of other signals from the mill to the translator the mill could thus be made completely automatic, with no operator control at all. Patents for ideas on this have already been taken out.

Another BISRA licensee, the English Electric Co, have developed the principle into a whole range of programming equipment based on a brick type construction utilizing plug-in standard units, which are already in production. For Colville's mill they have completed a system of their own which controls the screwdown and gates, and they are convinced that a whole mill can be automated.

New controls help tube making

A control system using Warner electromagnetic brakes and clutches to provide either continuous or batch production on a roller hearth annealing furnace has proved very successful over several months of operation. Designed by Birlec Ltd for

MANUAL CONTROLS ABANDONED Alternative manual controls or standby units are dispensed with on Talbot Stead Tube Ltd's new roller hearth annealing furnace. About a ton of steel tubes an hour can be driven through this heating chamber by remote control while the temperature is regulated by the four valves on the side



Swedish missile team at Shorts

H. G. Conway (left), deputy managing director and chief engineer of Short Brothers & Harland Ltd, shows one of the electronic analogue computers used by the company in missile development to members of the Swedish Guided Missiles Mission during a recent visit

Talbot Stead Tube Ltd's Walsall stainless steel mill, the furnace, which is gas fired, has turned out tubes up to 40 ft long and 8 in. outside diameter by remote control at the rate of a ton of steel an hour. No manual controls or standby units are fitted. Unlike previous furnaces used by the company it relies entirely on the electronic controls.

Four sections make up the furnace—a loading table, furnace chamber, spray quench booth and unloading table—and tubes are carried right through by a series of chain driven rollers. The 40 ft furnace chamber, which is pressurized, is divided into four zones. By means of specially designed control valves the products of combustion form a controlled atmosphere, thus doing away with any supplementary gas plant. This produces a controlled oxidation on the steel surface and pickling time is considerably reduced. The chamber is a long one to keep at 1100° C, the operating temperature, throughout, but Talbot Stead's have found that the variation is only 2 or 3 degrees over the whole length.

Vital to stop skidding

Six clutches and two brakes are used to allow the whole furnace to be remotely controlled to a given operating sequence. One of the biggest problems which had to be faced was the fact that during the acceleration and deceleration of the rollers in the individual sections it was absolutely vital to avoid the rollers skidding and, consequently, scoring the tubes. The roller system in each section called for a high starting torque characteristic but once the rollers begin to revolve the driving torque falls to approximately 50 pc of the starting torque figure. To accommodate for this, it was necessary to provide an electronic closed loop servo controlled system for the main drive clutch and the high speed drive clutch so that at all times the rollers were accelerated and decelerated at a controlled rate to prevent the tube skidding on the rollers. All the other clutches revolve at very slow speeds and are controlled by preset potentiometers to give the optimum driving torque and protect the drive chains, etc.

Servos control roller speeds

During continuous operation, the clutches of each of the four sections are engaged to enable the main clutch to drive the whole furnace so that the tubes are continually passing through the furnace. For batch production tubes which have been placed on the loading table are driven into the furnace chamber by engaging the main drive clutch and also the furnace clutch. When the tubes have moved into the furnace, an electronic counting device causes the drive to be stopped, and an automatic sequence is initiated which causes the oscillating drive clutch to be engaged and the motor started. This drive causes the furnace rollers to be turned backwards and forwards a predetermined amount by the reversing of the oscillating motor. During the time that the tubes are in the furnace, a second batch of tubes can be loaded on to the loading table. When the correct time has elapsed, the operator causes the high speed clutch to be engaged together with the furnace and spray quench clutches so that the tubes are rapidly withdrawn from the furnace and deposited in the quench section. The counting equipment operates as before to stop the drive when the tubes are in the correct position for quenching. The tubes on the loading table can now be driven into the furnace chamber. After quenching the tubes are driven onto the unloading table by means of the high speed clutch and motor.

An electronic servo arrangement comes into action whenever the main clutch or high speed clutch is engaged. This allows controlled acceleration and deceleration to be achieved irrespective of the load which the clutch has to work against. Normally, on any movement the sequence is that the load is accelerated to full speed in a period of between five and ten seconds. It then moves to a position just short of the required distance when it decelerates to a very slow speed, at which it moves forward to its final position. All the speed variation is obtained by control of the Warner clutches.

Several companies had a hand in the instrumentation. The three control desks, situated along the length of the furnace, were provided by Teledictor Ltd, who were also responsible for the electronic counting equipment. Westool Ltd make the Warner electromagnetic brakes and clutches and temperature and pressure are controlled by Honeywell pneumatic instruments.

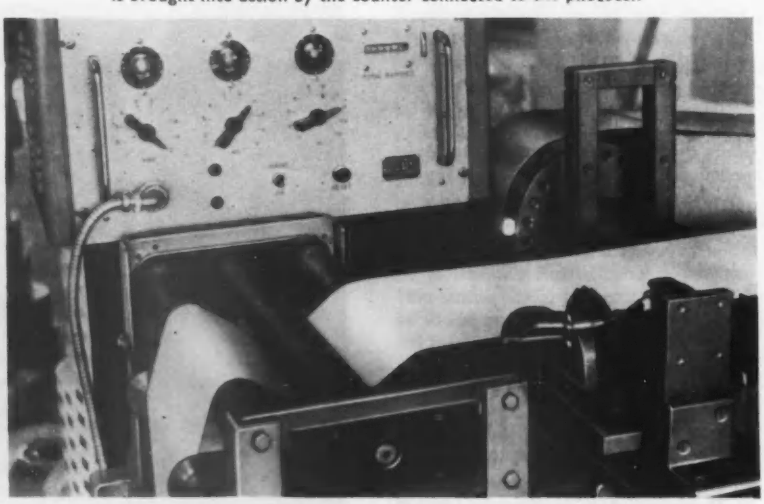
——LAMPSHADES——

Counter beats cutting problem

An ingenious use of a batch counter to overcome a production problem in lampshade manufacture is reported from a factory in Mitcham. One of the snags in making the covers is that the lengths must be cut just right—especially where pleated material is used—or the shade will either bag when mounted on the wire frame or suffer distortion by stretching. The company concerned—Waite & Son Ltd—have got round this problem with a device using a standard batch counter made by the Electronic Machine Co.

The material is wound from its original reel on to a second reel and in the process

MARKING EXACT LENGTHS The holes in the drilled wheel in front of the light source are spaced so that the notcher on the right marks the required length when it is brought into action by the counter connected to the photocell

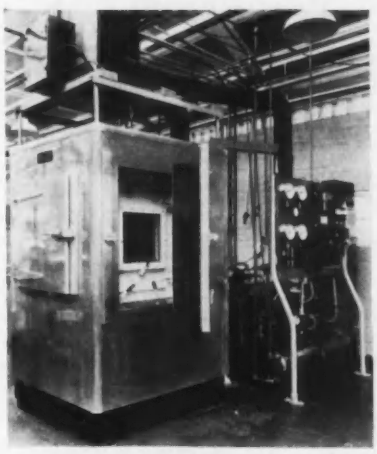


is notched on one edge at the predetermined length—in this case 78 in.—at which it is afterwards to be cut. This is achieved by using a metal wheel through which are drilled holes at intervals equivalent to the travel by the material, in the re-reeling process, of one inch. These holes run all round the wheel, which revolves between the photocell and light heads of the batch counter, each interval between the holes breaking the light beam and causing a count to be registered. The counter is set to seventy-eight and on completion of the batch a notcher comes into action and marks the material. After re-reeling, it is fed into a pleating machine and then passed under a guillotine which cuts it at the notch marks. Where other lengths are required it is purely a question of re-setting the batch counter by means of the dials.

AIRCRAFT

New tester simulates 100 000 ft

The more complex modern equipment gets the more necessary it is to spot faults at the development stage, even at the cost of



Pressure, temperature and humidity in this chamber can be closely controlled to simulate changes in climate and altitude

increasingly elaborate test gear. This is especially true in the aircraft industry, where components have to stand up to conditions which grow rougher every year. One of the relatively few companies which have facilities for testing their own and others' components—the Hymatic Engineering Co—have recently acquired a useful little altitude and climatic chamber which will simulate altitudes of over 100 000 ft and humidities up to 100 pc. Designed and constructed by J. & E. Hall Ltd, it has a capacity of 8 cu ft and has already been used for testing a variety of equipment such as pumps, valves and compressors for the aircraft and other industries. Temperature can be controlled over the range − 90° C to + 70° C with an accuracy of

Television tubes are simultaneously baked and evacuated at the Siemens Ediswan factory as the 159 exhausting cubicles travel continuously beneath the furnace; the tubes project into the furnace, where their temperature is slowly brought up to a maximum and then decreased

one degree either way, and control of pressure and humidity is very close. To stimulate 'breathing' of equipment all three quantities can be varied simultaneously. Pneumatic and electrical supplies are fed into the chamber so that components may be calibrated and viewed under full operating conditions.

CARS

UK controls for Russian plant

One of the features of the £12 million tyre factory which the British consortium Rustyfa is to build in Russia will be automatic hourly monitoring of the entire production. Electro-mechanical rather than electronic methods are to be used. About five hundred detectors will obtain production figures throughout the plant and scanning will be carried out using motor-driven uniselectors and relays of standard GPO type. The number of batches of rubber produced by the internal mixers, the numbers of yards of fabric, the number of extruded treads, or, in the case of giant tyre manufacture, the number of tread parts, the number of uncured and cured tyres and inner tubes, will all be checked.

Counting equipment will be centralized, and an adjacent office will be equipped with page printers where the hourly production totals will appear coded according to size or type. Additional overriding totals for each shift will also be produced and at these times something like a thousand characters of data will be printed out.

All the monitoring equipment is being supplied by Digital Engineering Ltd, whose performance recorders are manufactured under licence from the British Iron & Steel Research Association. The system was originally developed for the steel industry and is gaining ground there (see Metals section above).

TELEVISION

Tube output stepped up

The production of its millionth television tube by the Siemens Ediswan factory at Sunderland marks the end of three years' development in manufacturing techniques. The whole plant is now highly automated with production running at the rate of 12 000 tubes a week by less than 700 employees. Nearly two miles of overhead conveyors link a whole series of automatic processes and during a recent visit by CONTROL Mr Hitchberg, the works manager, said he felt the company had little to learn from German and American factories. Instruments from a variety of British companies are in use: Electroflo Meters supplied the majority of the temperature controllers, and controller-recorders employed in the furnaces include those of Engel & Gibbs, George Kent and Honeywell Controls.

IN BRIEF

ATOMIC ENERGY A PACE analogue computer has been bought by the Atomic Energy Authority for use at Harwell. Costing about £90 000 the computer was ordered from the European Division of Electronic Associates Inc.

COMPONENTS Prices of silicon rectifiers manufactured by Ferranti Ltd have been cut by an average of 15 pc.

AIRCRAFT Rolls-Royce's new high altitude test plant for turboprop and jet engines was formally opened by the Prime Minister, Mr MacMillan, on 27th September. First planned in 1954 it has cost over £5¼ million and is heavily instrumented.

CONTROL SYSTEMS A paper on the Describing Function Technique—used for assessing the stability of automatic control systems where at least one element is 'non-linear'—was read by Dr John West of Queen's University, Belfast, on 30th September to the Society of Instrument Technology.

METALS The American NRC type 912 vacuum fusion gas analyser for the determination of oxygen, nitrogen and hydrogen in metals is to be built in the UK by Wild-Barfield Electric Furnaces Ltd of Watford.

NOT IN THE DIRECTORY The telephone number of C.N.S. Instruments Ltd, of 61 Holmes Road NW5, omitted from the London directory, is as previously GULliver 2418.

CONTROL SURVEY 4

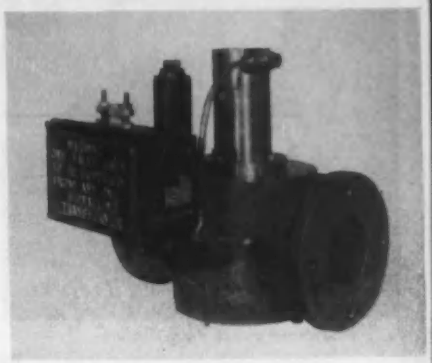
SOLENOID-OPERATED VALVES

Solenoid-operated valves are useful elements of electric control systems. They are two-position devices and not readily adaptable to proportional control, but they are widely used in on-off systems because of their simplicity and ease of supply.

Manufacturer	*Type Number*	*Description*	*Fluid*	*Diameter (std), in.*	*Max. operating pressure, lb./in²*	*Max. operating differential, lb./in²*
Alexander Controls Ltd *Reddicap Hill, Sutton Coldfield, Warwickshire*	SPC3	Three-way servo operated valve		$\frac{1}{2}$	150 (15 min)	5
	ACP4/6/7	High pressure valve		$\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$	450	6
	ACHL	Hand reset valve	High pressure hot water, oil steam	8 diameters $\frac{3}{8}$ up to 3 in.	250 for smaller valves varying to 100 for larger ones	3
Baldwin Instrument Co Ltd *Dartford, Kent*	HPV7/11	Three-way pilot valves (in balanced or unbalanced models)	Mineral oil, air	$\frac{1}{2}$	250	250
	V7/11			$\frac{3}{8}$	150	150
	LPV7/11			$\frac{1}{4}$	80	80
	ELPV7/11			$\frac{1}{16}$	15	15
	V23/11			$\frac{3}{8}$	150	150
	V23/17			$\frac{1}{16}$	150	150
Black Automatic Controls Ltd *Leafield, Carsham, Wiltshire*	LGM	Two-way	Town gas, methane propane, butane, air, etc	$\frac{1}{4}$ (BSP) female	100	
	AVG	Two-way		$\frac{1}{4}$, $\frac{3}{8}$ (BSP female)	50	
	LG	Two-way		$\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, 2, $2\frac{1}{2}$, 3, 4 (BSP female)		
Danfoss *13 Queensway, London, W2*	EVJ3	Two-way valve opened by direct pull of armature	Compressed air, gas, oil and water	$\frac{1}{8}$	284	240
	EV3			$\frac{1}{4}$	213	
	EVO6			$\frac{3}{8}$	43	
	EVG10/16/25/50			$\frac{1}{2}$/$\frac{3}{4}$/1/2	9/8/3/2·6	
	EVJ6/10	Two-way valve with servo operation		$\frac{3}{8}$/$\frac{1}{2}$/$\frac{3}{4}$/$1\frac{1}{4}$/2	213/142/213/142/	240
	EVSO10/16/25/35/50			$1\frac{1}{4}$/$1\frac{1}{2}$/2	142/142/142	
	EVM32/40/50					
Electro-Hydraulics Ltd *Liverpool Road, Warrington, Lancashire*	B.1000, B.2200	Two-way		0·04, 0·06,	6000, 4000,	
	B.1100, B.2300	Two-way		0·08, 0·10,	1500, 1000,	
	B.1200, B.2400	Three-way		0·125, 0·15 (orifice)	350, 250 (values lower for larger 3-way)	
	B.1300, B.2500	Two-way	Air, gases, oils, kerosene, petrol	0·25, 0·375	400, 100,	
	B.1400, B.2600	Two-way		0.5, 0.625	55, 25,	
	B.1500, B.2700	Three-way		0·75 (orifice)	12 (values about ½ for 3-way)	
	B.1900	Two-way	Gases, oils, petrol, kerosene	0·375, 0·5,	300, 150,	
	B.2000	Two-way		0.625, 0.75	60, 40	
	B.2100	Three-way		0·875, 1·0 (orifice)	25, 20 (values lower for 3-way)	
	B.3701–3710	Three-way	Mainly intended for oils and air	0·04, 0·06,	2000, 600,	
	B.3711–3715	Two-way		0·08, 0·10	250, 100	
	B.3716–3720	Two-way		(orifice)		
Ether Ltd *Caxton Way, Stevenage, Herts*	DF	Two-way pilot operated diaphragm valve	Town gas, propane, butane, water, air or light fuel oil	½ (orifice)	250	(2 min)
	MD	Two-way directly operated valve		$\frac{3}{32}$ (orifice)	100	
	HP10	Two-way directly operated	Water, air	¼, ⅜, ½, ¾, 1	20, 10, 5, 3, 1½	
	HP25			⅛, ¼, ⅜,	120, 40, 20	
	HP50			½, ¾, 1, 1½, 2 (orifice)	300, 120, 60, 40, 20, 10	
	TW25	Three-way directly operated valve	Water, air	0·13, 0·24, 0·36 (orifice)	100, 30, 15	
	TW50				250, 50, 20	
Flight Refuelling Ltd *Tarrant Rushton Airfield, Blandford, Dorset*		Two-way pilot operated valve	Hydrocarbon fuels but seals fitted for other liquids	8	150 (2 min)	
Graseby Instruments Ltd *Kingston Bypass Road, Tolworth, Surrey*	GW2	Two-way high pressure	Air	¼ BSP	2000	
Hydraulics & Pneumatics Ltd *Wulfruna Works, Villiers Street, Wolverhampton*		Three-way pilot valve	Air, oil		150	
Igranic Electric Co Ltd *Bedford, Bedfordshire*	H1	Two-way	Air, gas, water, oil or steam up to 135° C		150 (10 min)	
	H2	Three-way or four-way				
Jones Tate & Co Ltd *Victory Works, East Parade, Bradford*	Series 319	Two-way semi-balanced valve	Hot and cold water, steam, most gases including air and CO_2, liquids and refrigerants, etc	½, ¾, 1, 1½, 2, 2½, 3, 4	200	
Keelavite Rotary Pumps & Motors Ltd *Allesley, Coventry*	4669	Four-way pilot valve		¼	2000	
	1011	Three-way piston valve				
	1018	Three-way piston valve		⅜	250	
Lang Pneumatic Ltd *Victory Works, Birmingham Road, Wolverhampton*	SV1424	Three-way	Air	⅛ (orifice)	100	
	SV1536	Four-way	Air			
		Two- or three-way poppet valve	Air	½, ¾, 1 (BSP)		

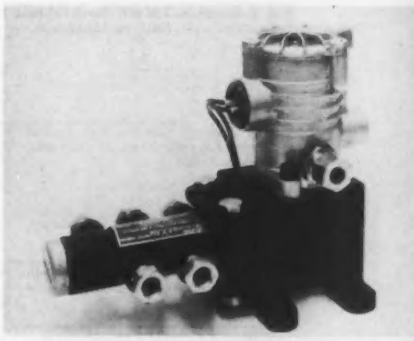
The valves are manufactured in numerous sizes and for many different fluids and applications. Generally the maximum operating pressure is about 300 lb/in², but for some models the valve is 2000 lb/in² and one manufacturer offers a valve for pressures up to 6000 lb/in². The pressure is only one of a number of possible criteria for a valve, which include frequency and time of operation, fluid flow, tightness of sealing, corrosibility of valve materials and seals, ease of maintenance, ability to withstand fire, heat, water or mechanical violence, power supplies, pressure drop and cost. Whichever of these decides the choice of valve, it will be surely found in the comprehensive range offered by British manufacturers.

Max. operating temperature, deg C	*Normally open or closed*	*Voltage (std), V*	*Power consumption, W*	*Remarks and special features*
82	ACR	250 a.c. or d.c.	10	Weatherproof and flameproof models available.
204	Closed	220 d.c.	50	The SPC3 has an operating frequency of 300 cycles /minute
204	Closed	250 or 440 a.c. or d.c.	16	Manually opened—electrically maintained—automatic closing
90	Closed	10–115 d.c. Power packs supplied for a.c. and d.c. voltages greater than 115	6	The pilot valves may be used to control small single-acting cylinders directly, or combined with a larger capacity 3-way or 4-way directional control valves so that there is a complete range ($\frac{1}{8}$–1 in. bore) for pressures up to 250 lb/in². Frequency of operation is 600 cycles/minute
	Closed ACR	230/250 a.c.		The LGM has an overall height of 2½ in. The LG series of main gas valves can be supplied with hand reset, by-pass and safety switch fittings, and flanged connexions (4, 5, 6 in.). Other voltages or non-standard valves to order
	Closed	190–250 a.c.		
90	Closed	220 or 380 a.c. or d.c. (EVJ a.c. only)	8 10 10 10/10/22/22 8 10/10/22/22/22 10/10/10	Available with a variety of connexions and special voltage coils
	Closed Open ACR	4, 24, 80, 110, 180, 230 d.c.	24	Metal valves and seats with direct operation of valve All the solenoid valves operate at a frequency of 400 cycles/minute
	Closed Open ACR	24, 80, 110, 180, 230 d.c.	33–43	Bonded rubber valves and renewable seats with direct operation of valve
	Closed Open ACR	24, 80, 110, 180, 230 d.c.	50–75	
	ACR Open Closed	10	6	Intrinsically safe valves with metal seats, certified for safe working. These form the basis of a range of ½, ¾ and 3 in. valves with servo operation
40	Closed	200–250 a.c.		
40	Closed	50–450 a.c. 6–250 d.c.		Non-standard valves for different voltages, operating temperatures, fluids and pressures can be obtained. Buxton certified flameproof enclosures are available. A miniature three-way valve TM has been added to the TW range
40		50–450 a.c. 6–250 d.c.		
70	ACR	220 a.c.	30	The valve has an extremely light weight of 220 lb. Manual over-ride fitted. 3, 4 and 6 in. models are under development
		24 d.c.		Lightweight
		110, 220, 440 a.c. or any other voltage 200–240 a.c.	1330 VA 10	
135	Closed	100/550 a.c. or d.c.	15–52	Each valve is fitted with a strainer ahead of the valve. Both valves are servo operated
60	ACR	20–500 a.c. or d.c.	190, 260, 330, 440, 660, 770, 1050, 1200	Smaller solenoids can be supplied for lower operating pressures. Weatherproof and flameproof constructions available. Special valves up to 2000 lb/in² or elevated temperatures, including superheated steam. 3 and 5-port, direct acting, 3 port poppet, mixing, quick-operating and non-standard valves can be supplied
90		6–440 d.c. 12–500 a.c.	18	Single or double solenoid operation is available for the 4669. The 1011 is a 3-port and the 1018 a 5-port valve.
	ACR	8–550 a.c. 8–110 d.c.	7½	Single or double pilot solenoid operated four-way valves with spring or pressure return can be supplied with ports ½, ¾, 1 in. BSP

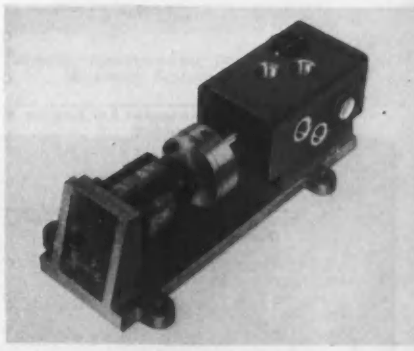


This 3 in. valve is controlled by a small pilot valve with a low power consumption (*Electro-Hydraulics Ltd*)

A mechanical linkage leads to a positive and rapid action on this valve (*Teddington Industrial Equipment Ltd*)



A solenoid-operated cylinder valve that can work under water (*Maxam Power Ltd*)

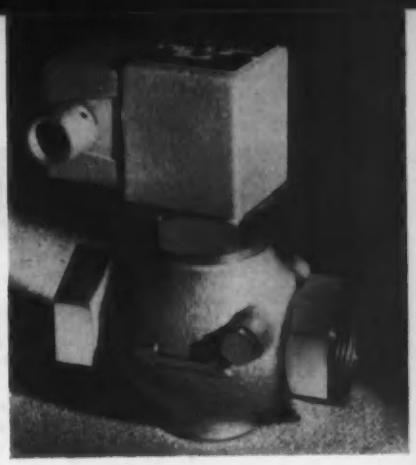


A ¾ in. solenoid-operated piston valve with five ports (*Keelavite Rotary Pumps and Motors Ltd*)

[*continued overleaf*

Solenoid-operated valves (continued)

Manufacturer	Type Number	Description	Fluid	Diameter (std), in.	Max. operating pressure, lb./in²	Max. operating differential, lb./in²
Magnetic Valve Co Ltd *28 St. James's Place, London, SW1*		Two-way single beat stop valve	Water, steam, oil, gas, air, according to valve and materials used in construction	¼, ⅜, ½, ¾, 1, 1¼, 1½, 2, 2½, 3	100	5
	'P'	Two-way high pressure stop valve		¼, ⅜, ½, ¾, 1, 1¼, 1½, 2, 2½, 3, 4, 6	100 (10 min)	10–100
	P PR	Two-way high pressure stop valve		1		
		Balanced three-way valve (4 or 5 ports)		½, ¾, 1	100	
		Balanced two-way regulating valve		½, ¾, 1, 1¼, 1½, 2, 2½, 3, 4	100	70
		Safety cut-out valve with hand reset		¼, ⅜, ½, ¾, 1, 1¼, 1½	250	
	R (high pressure type)	Two-way single beat stop valve		¼, ⅜, ½, ¾, 1 ($\frac{4}{10}$ in. std. orifice)	250	250
		Two-way by-pass valve		¼, ⅜, ½, ¾, 1	100	
Martonair Ltd *Parkshot, Richmond, Surrey*	S.557	Three-way	Air	⅛ BSP	230	
Maxam Power Ltd *Redruth, Cornwall*		Three-way pilot valve	Air	$\frac{3}{16}$, $\frac{5}{16}$, ¼ (orifice)	150, 90, 60	
		Two-way pilot valve			250, 175, 125	
		Two-, three- and four-way directly operated valves	Air	¼ (BSP) Two-way also in ½ (BSP)	100	
Rheostatic Co Ltd, The *Slough, Buckinghamshire*	AM	Two-way single beat valve (semi-automatic)	Primarily oil to burners	⅜, ½, 1	30, 10, 5	30, 10, 5
	AMA	Two-way single beat valve			30, 3, 3	30, 3, 3
	GV	Two-way	Primarily for town gas	⅜, ½, 1, 1¼	½	½
Sauter Controls Ltd *70 Dudden Hill Lane, London, NW10*	VS12 VS133 VS33 VS34 VS35 VS76	Two-way directly operated valve Two-way servo operated valve	Light fuel oils, air, refrigerants, etc.	$\frac{11}{64}$ $\frac{5}{32}$ $\frac{7}{32}$ (port diam.) $\frac{33}{64}$ $\frac{43}{64}$	145	All 145 except VS133 which is 110
Schrader's Son, A. *829 Tyburn Road, Erdington, Birmingham 24*		Four-way valve	Air	¼, ⅜ (BSP)	20–130	
S.E. Laboratories Ltd *606 North Feltham Trading Estate, Feltham, Middlesex*	ES100, ES100R	Two-way servo operated	Gas or liquid		4000	
	ES101	Three-way servo operated			3500	
	ES104	Three-way servo operated			3500	
	ES105, ES105R	Three-way directly operated		0·162 (orifice)	1500	
Smiths Jacking Systems Ltd *Jackall Works, Edgware Road, Cricklewood, London, NW2*	X.79850/3	Two-way disc type valve	Mineral oils	½ gal/min	1500	
	X.82774			½ gal/min	1500	
	X.82775	Four-way spool valve	Mineral oils	½ gal/min	1500	
	X.87852	Two-way spool valve	Mineral oils	2 gal/min	500	
	X.90856	Four-way cone type balanced valve	Mineral oils	5 gal/min	2000	
Stuart Davis Ltd *Much Park Street, Coventry*	LO.133B.Mk2	Three-way valve (five ports)	Air	¼ (BSP)		
Teddington Aircraft Controls Ltd *Cefn Coed, Nr. Merthyr Tydfil, Glamorgan*	FGB	Two-way	Fuel	¼ (BSP)	150	
	FAW	Two-way	Fuel or water	¼ (BSP)	30	
	ES	Three-way	Air	¼ (BSP)	350	
	FKF	Two-way	Air	¼ (BSP)	500	
Teddington Industrial Equipment Ltd *Sunbury-on-Thames, Middlesex*	YF (two-way)	Servo operated—full bore	Air, town gas, water, light fuel oils and most non-corrosive fluids except refrigerants	¾	250 (3 min)	
		Low pressure—full bore		¾ (valve seat)	5	
		Low pressure for gas		1	12 ft head	
		High pressure—small bore		$\frac{1}{16}$	350 (20 min)	
	OMA	Two-way directly operated valve	Ammonia, etc	¼, $\frac{1}{16}$, ⅜, $\frac{7}{16}$ (valve seat)	82, 49, 33, 14 (liquids)	
	OMR		All refrigerants except ammonia			
	OMW		Water, light oils and low pressure steam			
Transmission Accessories Ltd *Leighton Buzzard, Bedfordshire*	SGA4	Four-way directly operated valve		¼, ⅜, ½, ¾ (pipe)	250	
	DSGA4	Four-way directly operated valve				
Vickers Ltd *Vickers House, Broadway, Westminster, London, SW1*	DSCV	Two-, three- or four-way directional valve		¼ to ¾	1000 (balanced spool) 3000 (normal spool)	
	CVS	Two-, three- or four-way pilot operated valve		½ to 2	3000 (1000 pilot)	
	CVS/2	Three- or four-way pilot operated valve		½ to 2	3000 (1000 pilot)	
Western Manufacturing (Reading) Ltd *The Aerodrome, Reading, Berkshire*	HP345100	Three-way	Oil	¾	1500	
	HP137100	Two-way	Oil	¾	1500	
	HPC124100	Four-way	Oil	¼	1500	
	HP358100	Four-way	Oil	$\frac{5}{16}$	1500	



Designed to control the flow of town gas (*The Rheostatic Co Ltd*)

Max. operating temperature, deg C	*Normally open or closed*	*Voltage (std), V*	*Power consumption W*	*Remarks and special features*
149	ACR	all usual voltages		The range of valves is large with a wide variety of non-standard fittings and coils. Many of the valves can be obtained in flameproof solenoid enclosures
149	ACR			
149	ACR			
149	Closed			These can also be supplied up to 12 in. diam. for use with town's gas
149	ACR			
149				
149	Closed (with by-pass)			Also supplied in gas and low pressure types
50	Closed	Various coils for range 6–400 a.c. or d.c.	12	This basic unit can be fitted to a range of 3- and 5-port valves with single or double solenoid operation, and which are fully or supply balanced. These valves are suitable for hydraulic operation, but the basic unit must have a supply of air
	Closed	110, 220, 440 a.c. or any other voltage	7	The pilot valves can be supplied in the normally open position and can be fitted to ¼ and ½ in. directional control valves (three- and four-way). These directional control valves are available with double solenoids and spring or pressure return The four-way valve can also be supplied with double solenoid operation
72	Closed	All usual voltages	12	¾ and 1 in. valves can be supplied for the control of certain gases where a dead tight shut-off is essential
40	Closed		18 VA	
60 (special models up to 100)	Closed	230/240 a.c.	12 19 15 15 15 18	The coils are damp-proof and the valves are leak-proof. Non-standard models can be supplied
		12, 24, 110, 220, 440 a.c.	16	Non-corrosive materials. Mounted in any position. Balanced poppet type spool
70	ACR	18–28 d.c.	12	ES.101, ES.104, ES.105 and ES.105R are solenoid venting valves, the last two types being primarily designed for aircraft and missile applications, and have an operating frequency of 600 cycles/minute
70	Open	18–28 d.c.	12	
70		18–28 d.c.	14	
70	ACR	18–28 d.c.	24	
	ACR	6, 12,20 24, 30, 36, 48 d.c.	60 (intermittent)	Alternative voltages for the X.90856 can be supplied to special order
	Closed		75 (intermittent)	
	Open	230/250 a.c.	16	
	Closed	230/250 a.c.	90 VA	
		230 or 440 a.c.	775 VA	This valve can be supplied for double solenoid operation, and has been designed for heavy duty
	Closed	24 d.c.	6·5	These valves are primarily designed for use in aircraft. There is also a wide variety of hot air gate valves
	Closed	16–19 d.c.	12	
100		24 d.c.		
100	Closed	24 d.c.		
40	Closed	110 or 225 a.c.	2·2	
121	Closed	225 a.c. or 240 d.c	18	
100		110, 230, 440 a.c. and d.c. other voltages to order	300	The SGA4 is also available for dual pressure installations. The DSGA4 is a double solenoid momentary contact valve. Sub-base mounted. Special spools and sleeves fitted so that there are no seals on the moving parts, and the operating frequency is 300 cycles/minute.
		All usual voltages		The CVS/2 is a double solenoid, three-position valve and is available with input or output by-pass or open centres
71		24 d.c.	17	These valves are designed for use in aircraft hydraulic systems. The four-way valves are double solenoid, four-position types
71		24 d.c.	18	
71		24 d.c.	12	
71		24 d.c.	17	

A flameproof enclosure is the explanation for the size of this single beat stop valve (*Magnetic Valve Co Ltd*)

Two-way operation up to 450 lb/in² (*Alexander Controls Ltd*)

A strainer is fitted to the entry side of this three- or four-way valve (*Igranic Electric Co Ltd*)

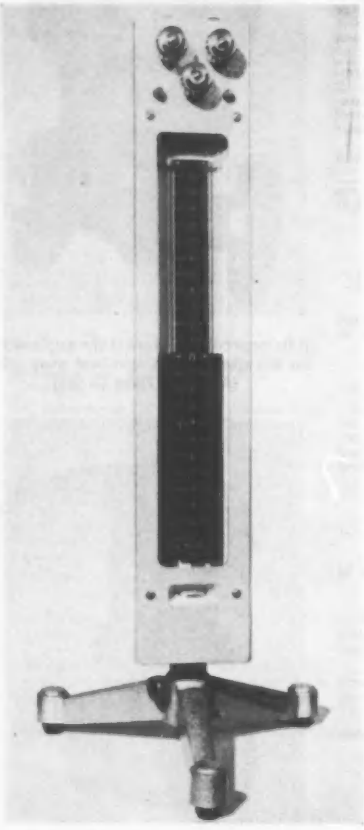
New for Control

A monthly review of system components and instruments

MANOMETER

low priced, versatile

A low-priced manometer which can be simply and quickly arranged for flush panel, wall mounting or for laboratory bench work, has been developed by Refinery Equipment and Speciality Co Ltd. The instrument is intended for the measurement of pressure, differential pressure and levels



The manometer is shown fitted with a stand for laboratory bench work

at system pressures up to 100 lb/in² gauge. Each instrument is tested to 200 lb/in² gauge. The equipment includes two line-isolating valves and one equalising valve, and a simple foolproof system for filling and venting the measuring fluid used. Three standard instruments are available with scales of 6 in., 12 in. and 24 in. respectively; alternative scales 15 cm, 30 cm and 60 cm and 0–100 sq. root. A free travel of 1 in. on each scale permits easy zero-adjustment. The cast aluminium case of the manometer is provided with two 'built-in' safety features —a transparent, plastic front and an adequate drainage and vent hole.

Tick **No 147** on reply card

PERMANENT RELAYS

addition to P.O. range

The Post Office type 3000 and 600 relays made by the Telephone Manufacturing Co Ltd are now available fitted with special 'remanent' cores which enable them to latch up on receipt of an impulse; to remain so indefinitely and to be capable of withstanding a high degree of shock and vibration, until a cancellation signal is received. The remanent relays can be supplied fitted with two windings so arranged as to provide operating and release voltages from the same battery supply.

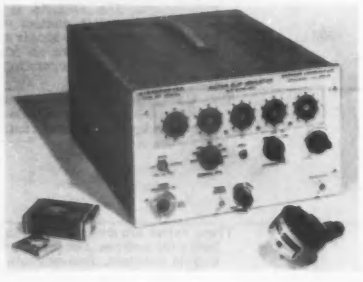
Tick **No 148** on reply card

MOTOR SLIP INDICATOR

accurate, fast indicating

Precise measurement of electric motor slip can be made automatically in a fraction of a second with the new transistorized Dynaset instrument, developed by the Dynapar Corporation. Accurate to one part in a thousand, motor slip can be read directly in large illuminated digital numbers on a panel through neon tubes. It reads resolutions in percentage: 4 digit–0·01 pc; 5 digit–0·001 pc. For greater accuracy, motor slip may be read in resolutions up to a few parts in 100 000 merely by increasing the measuring time. The indicator is connected to the motor shaft through a small electrical wire, and a rotary pulse generator having a torque of 1 in. oz. Standard units measure motor speeds from 600 to 3600 r.p.m. with full accuracy. For special applications it can measure slip to one part in a thousand in 1/60th of a second by using a 1000-tooth rotary pulse generator. Operation of the instrument centres around two variables,

The motor slip can be read directly in large illuminated digital numbers



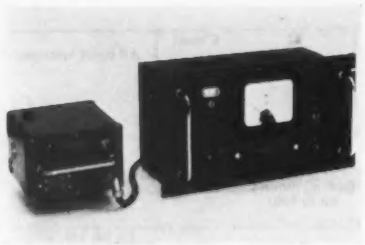
frequency and motor speed. The proper count interval (depending on motor speed) is shown by the r.p.m. selector on the panel. There is no time delay at start of count, enabling user to select any predetermined instant at which to initiate the action.

Tick **No 149** on reply card

GAMMA RAY ELECTROMETER

measures ore concentration

A gamma ray electrometer has been developed by Electronic Instruments Ltd in conjunction with the United Kingdom Atomic Energy Authority, to meet a special requirement for measuring the concentra-



These electrometers are being used in uranium processing plants

tion of uranium ore in a slurry. The measurement has to be made whilst the slurry flows through a steel pipe in an ore treatment plant. The absorption of the gamma rays in the pipe varies with the density of the slurry. This change in absorption, however, is small compared with the total gamma ray flux incident on the ionization chamber. Therefore, an instrument is required which will measure a small change in the presence of a large signal. The electrometer is designed around the E.I.L. Vibron unit, an electromechanical device which replaces the electrometer valve and provides a higher degree of sensitivity and stability than can be attained by conventional valve circuits.

Tick **No 150** on reply card

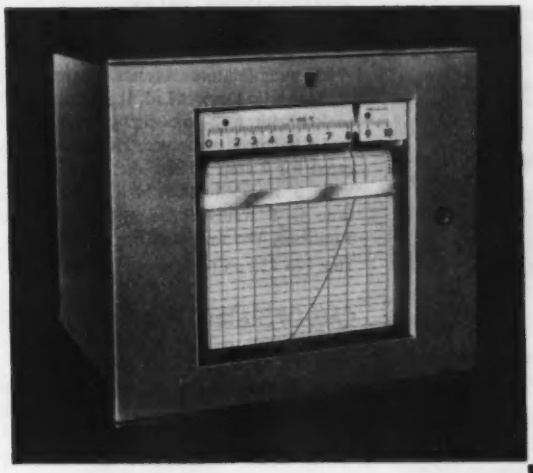
BELLOFRAM SEALS

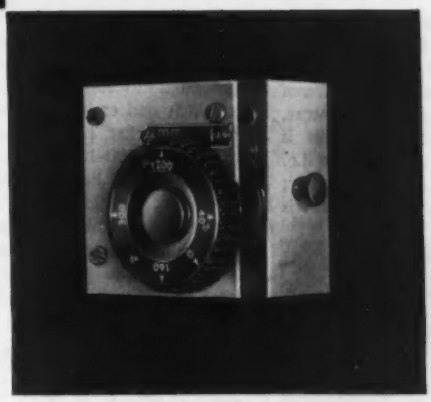
bellows + diaphragm

An interesting new product which will shortly be in production is the Bellofram seal. This seal is a long stroke, deep convolution, constant area diaphragm, which is free positioning with complete relaxation within its stroke. It is responsive to small pressure changes, has almost no mechanical spring gradient and possesses a long stroke and flexing life. It is claimed

Tick **No 34** on reply card for further details

Change chart speed the easy way with this potentiometric recorder by PHILIPS





Turn the knob to change the chart speed. Four position gearbox—a built-in feature of all Philips Potentiometric Recorders.

De-clutch, *change gear* and resume. That's all you do to alter the chart speed in Philips Potentiometric Recorders and Recorder-Controllers. And it takes about the same time as it requires to read this sentence. The paper speed is indicated in mm/hour for each position of the precision-made four-speed gearbox, and from a range of standard gearboxes you can also specify the ratios best suited to your purpose. This is only *one* of the features which have made Potentiometric Recorders by Philips so increasingly appreciated. But above all they are dependable—instruments designed and constructed from the start just to go on working. If you are looking for this kind of reliability plus laboratory accuracy we will gladly tell you more.

Write now for fully descriptive literature.

PHILIPS

Regd. Trade Mark of Philips Electrical Ltd.

Sole Distributors in U.K.

RESEARCH & CONTROL INSTRUMENTS LTD.,
Instrument House, 207 King's Cross Road, London, W.C.1
Telephone : TERminus 8444
Telegrams : RACIL KINCROSS

(RCL0378)

that the seal performs the function of both a bellows and a diaphragm, and yet is superior to both in a number of respects. The seal is precision moulded from high-grade oil and heat resistant synthetic rubber, reinforced with high tenacity fabric material.

The Bellofram seals are to be made in this country by George Angus & Co Ltd, who have obtained a licence for this purpose from the Bellofram Corporation, Massachusetts, U.S.A.

Tick **No 151** on reply card

VALVE VOLTMETER

first of its kind

Marconi Instruments Ltd have announced the latest addition to their range of voltmeters. The new equipment, vacuum tube voltmeter (type TF 1041B), is claimed to be the first instrument of its kind with a frequency range extending to 1500 Mc/s. The a.c. measurement range is 25 mV to 300 V, 20 c/s to 1500 Mc/s. The instrument measures d.c. voltages from 10 mV to 1000 V, and resistances from 0·02 ohm to 500 megohms. Multipliers can be supplied for up to 2 kV a.c. and 20 kV d.c. Both a.c. and d.c. inputs are isolated from chassis. On all d.c. ranges a centre-zero facility is available to aid the precise determination of null-point in bridges or discriminators. Measurement of d.c. volts and ohms is simplified by the special dual-purpose d.c. probe with its fingertip volt/ohm selector; with it set to volts an isolating resistor is

The voltmeter has a sensitivity to match its smart appearance

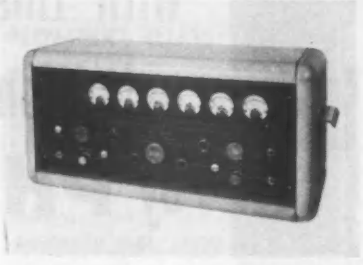
introduced to shield the circuit under test from the effects of probe-lead capacitance. The d.c. supply for ohms measurement is obtained without the use of batteries. The frequency response is flat to within 1 dB up to 1000 Mc/s and shows a rise of less than 3 dB at 1500 Mc/s.

Tick **No 152** on reply card

MICROSECOND STOPCLOCK

transistorized, self-checking

A transistorized microsecond stopclock has been recently introduced by Venner Electronics Ltd. The equipment can measure pulse widths, mark/space ratios, period of pulse or other waveforms having amplitudes between 0·75 V and 500 V peak. Almost any type of time measurement can



This transistorized stopclock is smaller than any comparable valve equipment

be carried out on contacts without the use of ancillary power supplies. The equipment is inherently self-checking on the applied waveform and has, in addition, six internally generated waveforms which are brought via a switch and emitter follower to a panel mounted socket. The frequencies concerned are 1 Mc/s, 100–10–1 kc/s and 10 c/s. The time range of basic equipment is from 3 microsec to 1 sec, but this can be extended to 27·8 hours if required. It can be supplied to operate from 12 V d.c. or 230 V a.c. The input impedance is 250 kilohms and the unit can be used for single or two line working.

Tick **No 153** on reply card

TERMINATING GLANDS

for flameproof equipment

The Telegraph Construction & Maintenance Co Ltd have announced the introduction of their FG range of glands developed in conjunction with the Light & Power Accessories Co Ltd. The FG range of glands has been designed for use with flameproof equipment and may be used in conjunction with either plastic, or rubber insulated and sheathed, steel wire armoured cables. The glands comply strictly with BS.229 and have been approved by the Buxton Authorities for use under Group 2 and Group 3 conditions. The design is claimed to be technically in advance of any similar gland at present marketed, in that an internal flameproof escape path for gases has been incorporated, the length of the path being 1·000 in. (min) and the width of the path 0·0035 in. (min)–0·007 in. (max). As in the G and B series of glands, the armour wires are clamped between two cones and will withstand a tension appreciably greater than that specified in Clause 4 of BS.542. This clamping device also ensures excellent earth continuity between the armour and the gland. To prevent the ingress of moisture, a seal on to the outer sheath of the cable is provided, thus guarding against corrosion of the armouring wires.

Tick **No 154** on reply card

SUBMINIATURE RELAY

minimum size and weight

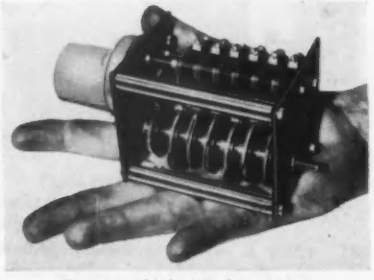
A new subminiature relay has been produced by Magnetic Devices Ltd. It is hermetically sealed with a 2-pole change-over action and a balanced armature. The contacts are rated for 2 amp at 28 V d.c. or 110 V a.c. with a non-inductive load. The pull-in time is 5 millisec and the drop-out is 3 millisec. The weight of the unit is $\frac{1}{3}$ oz.

Tick **No 155** on reply card

CAM-OPERATED TIMER

smallest on the market

A miniature synchronous cam-operated timer has been introduced by Electrical Remote Control Co Ltd. The timer (type MSC) has a switching capacity of 10 amp



Compact, high switch capacity

at 250 V a.c. in each of the six change-over switch circuits. It can be supplied with up to 12 adjustable cams and change-over switches, and with a final shaft speed of between 1 revolution in 5 seconds and 1 revolution in 28 days. The manufacturers are of the opinion that the unit is, despite its high switching capacity, the smallest on the market.

Tick **No 156** on reply card

VARIABLE SPEED DRIVES

now available up to 10 h.p.

Lancashire Dynamo Nevelin Ltd have announced an extension to their range of Varimag variable speed drives, which until now have been limited to outputs up to 2 h.p. operating on a single phase a.c. supply. The Varimag variable speed drive has now been developed as a three-phase unit and is available for outputs up to 10 h.p. The drive comprises a speed controller and a variable speed motor. Basically, the controller is a magnetic amplifier giving a variable voltage output

Tick **No 35** on reply card for further details

PNEUTECHNIQUE

3 automatic compound controllers give greater flexibility, more accurate control

These Negretti & Zambra Compound Controllers fulfil the definite need in industry for flexible, accurate automatic control. Operating on a clean, dry air supply at 20 p.s.i., they make automatic control of industrial processes easy, rapid, and convenient. In all three models the various units are standardised—so a model selected for a particular application can be readily adapted to others.

1 **BASIC CONTROLLER :** ***for use when manual control is not required.***

2 **CONTROLLER :** ***incorporating facilities for manual control internally.***

3 **CONTROLLER :** ***with auto/manual test facilities mounted externally on a sub-panel.***

Set-up procedure is extremely simple — a particular advantage where it is necessary to close down the plant periodically, as resumption of automatic control can be rapidly effected. Further advantages are :

- **NO INTERACTION BETWEEN TERMS,** ***enabling the controller to embrace wider plant characteristics than are possible with interacting controllers.***
- **IDEAL BASIC CONTROL RESPONSE** ***generated under all conditions.***
- **TRUE VALUES** ***of Proportional Band and Integral and Derivative Action Times are calibrated on the various units.***
- **OPTIMUM PLANT CONTROL** ***can be methodically and rapidly effected.***
- **TRULY CALIBRATED PLUG-IN UNITS** ***allow easy replacement without re-setting and facilitate servicing.***
- **EASILY CONVERTIBLE** — ***thus a two-term controller may be used with either Derivative or Integral Unit, and three-term controller with both units.***
- **SELF-CONTAINED UNITS,** ***compact and self-purging. FORCE-BALANCE PRINCIPLE of operation involves no levers and friction losses, the diaphragm assemblies giving high sensitivity.***

• • •

We will be pleased to send you a copy of our fully illustrated booklet No. R 35/2 on your request.

NEGRETTI & ZAMBRA

THE NAME THAT MEANS PRECISION ALL OVER THE WORLD

Agents or subsidiaries in all major countries

Factories at Barnsbury, London, N.1 · Aylesbury, Bucks, Chobham, Surrey
Head Office: 122 Regent Street, London, W.1
Telephone: REGent 3406

from a three phase, bridge connected, semi-conductor rectifier, the level of voltage being determined by the setting of a hand-operated potentiometer. The magnetic amplifier is connected in such a way that the armature voltage of the variable speed motor is in constant balance with the reference obtained from the speed potentiometer. Any difference existing between these two levels of voltage results in a signal into the magnetic amplifier in such a direction as to correct the error. The speed controller is a static piece of robust equipment, and for the larger outputs makes use of silicon semi-conductor rectifiers. The three phase Varimag is available from 3 h.p. up to 10 h.p. and provides a speed range of 20/1. The variable speed motor may be switched direct-on at any speed and any load, and will provide a speed regulation light load to full load of $\pm 2\frac{1}{2}$ pc. The motor can be provided in protected enclosures or totally enclosed.

Tick **No 157** on reply card

CABLE TEST SET

portable, convenient

A new cable test set provides, in easily portable form, the facilities for checking the continuity and insulation of multi-core cable looms. Although initially designed for checking electrical systems in aircraft, the unit is of particular value in any type of installation where cabling is already in place, or where the cable runs are in confined spaces. Either a continuity or an insulation check can be carried out from one end of a cable run, the far end being terminated by a small unit weighing less than $\frac{1}{4}$ lb. A test is initiated by a press button and the instrument automatically selects each wire in turn. The identification of the core undergoing test is indicated in a window which is illuminated by a red light if failure occurs, in which case the selector stops at the faulty core. Successful completion of a test sequence is indicated by the extinguishing of a separate indicator lamp. A reset button prepares the test set for a further test sequence. A single outlet from the test set can be adapted for use with any cable by means of a suitable coupler. In the case of a connector having a multi-position keyway (e.g. Plessey Mk IV) the coding is checked by a clearly marked movable keyway on both the coupler and termination units. To enable long cable runs to be tested in conditions where the termination unit is more conveniently attached by a second operator, an intercommunication amplifier is incorporated in the instrument, connection being made via the cable under test. Standard service style headsets may be used. When this system is in use the operators receive an additional audible signal as each test is made and can distinguish when a cable failure is detected. The cable test set is portable and supplied in a smartly produced case. The

A useful aid for checking cable continuity

power supply can be from a battery or a normal mains supply. The unit is made by de Havilland Propellers Ltd.

Tick **No 158** on reply card

HIGH-PRESSURE VALVE

long life, simple maintenance

A recent addition to the Hydraulics and Pneumatics Ltd range of valves for liquid and gases is the high-pressure full flow valve. The valve has flanged or socket ends and can be obtained in diameters from 3/32 in. to 4 in. Pressures may vary between 140 and 5000 lb/in². The shut-off unit is a spherical metal ball with a hole through it. In the open position this hole registers with the bore of the pipeline, and the liquid or gas flows without turbulence. The ball is mounted in two annular discs, concentric with the pipeline, which form a seal in both directions when the valve is closed. The spindle which turns the ball passes through a seal above the ball and fits a cruciform

This valve can accept pressures of up to 5000 lb/in²

slot in it. By resetting the spindle in the cruciform slot, the valve may be adjusted for clockwise or anti-clockwise closing. A three-way or four-way valve is also made, working on the same principle.

Tick **No 159** on reply card

AIR GAUGE

flexible pneumatic control

The new model 88 pneumatic size control equipment is the latest addition to the range of air gauges being manufactured by Teddington Industrial Equipment Ltd. It is sensitive, robust, and provides a flexible control for grinding, fine turning and other manufacturing processes where the finished size of the product is important. The complete equipment comprises two units—the gauging head which is fixed to the machine and provides a pneumatic signal to a separate control unit. This control unit houses all the pneumatic and electrical components for the measurement and control of size. The signal from the gauging head operates pneumatic or electric relays of a new design and these

The control unit houses the pneumatic and electrical components

operate electric relays, each of which has a pair of change-over contacts. These contacts are wired to the machine controls to provide the required control action. Either two or four output relays are provided and each of these is adjustable and can be set to operate at any point in the range of the instrument, thus on a grinding machine the work cycle could commence with a coarse feed changing to a slower feed at a pre-determined point, with a wheel dressing operation initiated where required, and finally spark out to size. The final relay could be set at the lower tolerance limit to prevent out of tolerance parts being produced. Three light signals are provided which operate in sequence with the relays, red first at over-size, followed by amber and green, then amber again and finally red. The equipment has an adjustable amplification and may be used for any full scale range from 0·001 in. to 0·004 in. The equipment requires a clean dry air supply at any pressure between 50 and 150 lb/in² and this need not be regulated. An electrical supply of 230/250 volts 50 c/s is necessary or 110/115 volts 50 c/s. Contacts of the output relays are rated at 3 amps 250 volts a.c.

Tick **No 160** on reply card

Tick **No 36** on reply card for further details

For Machine Shop Applications—
Measurement and Inspection
Comparators,
Machine Control and
Servo Systems

A.C. Inductive Pick-Offs

LINEAR OUTPUT
NO WIPING CONTACTS
INFINITE RESOLUTION
ROBUST CONSTRUCTION

Ask for Sperry Brochure No. 767

SPERRY Precision Components

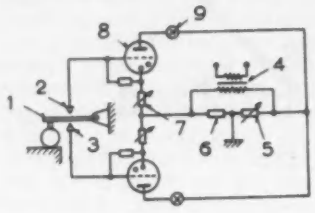
SPERRY GYROSCOPE COMPANY LIMITED · GREAT WEST ROAD · BRENTFORD · MIDDLESEX Telephone: EALing 6771

INVENTIONS

notes on recent patents in the control field

Arcing wear prevented

One of the disadvantages of contacts used for accurate measurement is the wear of the surfaces caused by arcing as the contacts are opened and closed. The arcing

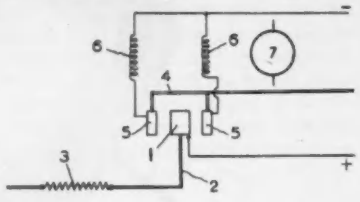


can be prevented by using a self-holding contact which, after being cut in, electrically bridges the switching contacts so that they are currentless and therefore protected. The disadvantage of this method of protection is that after a time the contacts may become heated by the flow of current which will also lead to the destruction of the contact surfaces. The patent claims to overcome both these disadvantages by the method shown in the diagram, where the contacts (1, 2, 3) of the gauging head of a tolerance-measuring instrument are connected across bridge circuits each of which becomes balanced when the appropriate contacts close; in this way the current through the contacts almost immediately ceases and they may be reopened without arcing. In the figure the upper-limit contacts (1, 2) are connected through earth across a bridge circuit supplied by a transformer (4) and having as its four limbs the two impedances (5, 6), the cathode resistor (7), and a thyratron (8) in series with the upper-limit indicating lamp (9). The lower-limit contacts (1, 3) are connected across a similar bridge. With the contacts open the thyratrons are non-conducting and the lamps are not lit. If the contacts close the potential across the impedance (6) is applied to the control grid of the appropriate thyratron which strikes on the positive half-cycles of the supply and lights the associated lamp. The thyratron ceases to fire when the contacts reopen.

796 517. Linear dimension gauges. **Censor Patent-und Versuchanstalt.** 11th June 1958.

Car driving made easy

A car is kept at a constant speed, within the limits of the engine, by a device fitted between the accelerator pedal and the engine throttle. A contact (1) is connected to the pedal through a linkage (2) and a spring (3).



A forked member (4) is moved by the speedometer and any deviation from the desired speed (or change in the pedal setting) will cause the centre contact (1) to make with one of the side contacts (5). This will energize one of the fields (6) of a split field motor, which will cause the motor armature (7) to rotate the engine throttle in the direction that will restore the car speed to that set by the accelerator pedal.

793 470. Automatic speed control. **Soc. Anon. A. Citroën.** 16th April 1958.

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, WC2. Price 3s. 6d. a copy (including postage, inland and abroad)

PEOPLE IN CONTROL

Mr T. P. W. Norris, formerly of the Vickers group, has been appointed Deputy Chairman of George Kent Ltd. **Mr W. A. Hartop** has been appointed Managing Director. **Cmdr P. W. Kent,** formerly Chairman and Managing Director, remains Chairman. **Mr R. E. Handford,** Deputy Managing Director, relinquishes his executive functions and retains his seat on the Board.

Mr Bruce Adkins, Publicity Manager of Elliott-Automation Ltd, has been appointed Public Relations and Information Officer to the European Nuclear Energy Agency, a department of the Organization for European Economic Co-operation, in Paris.

The first appointments to the new Electro-Mechanical division of the Sealey Engineering Co are announced as follows. **Mr P. Fatharly** as Manager and **Mr D. D. Searle** as a Development Engineer; both are lately of the Ministry of Supply and the Atomic Energy Authority. The new division is to undertake the designing, development and production of mechanisms and light electrical and electronic apparatus with special reference to control systems.

Dr R. L. G. Gilbert has joined the staff of the Engineering Department of Marconi Instruments Ltd, St Albans.

Mr Bowman Scott, Director of the Solartron Electronic Group Ltd, is on a seven-week visit to the USA and Canada, with a long list of firm inquiries about Solartron's electronic reading automaton and their automatic keyboard instructor. He will discuss the requirements of customers so that their representatives may visit Solartron's new works early in the new year, for consultation on production models.

Sir Alexander Fleck, Chairman of ICI and this year's President of the British Association for the Advancement of Science, has been appointed Chairman of the Minister of Power's Scientific Advisory Council.

Cmdr H. Pasley-Tyler, Joint General Manager of Elliott Brothers (London) Ltd, has been appointed to the Board of the Company.

Dr J. S. McPetrie has been appointed Director General of Electronics Research and Development, Ministry of Supply, in succession to Dr D. H. Black.

CMDR H. PASLEY-TYLER

BOWMAN SCOTT

DR R. L. G. GILBERT

BRUCE ADKINS